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WIND TUNNEL DEVELOPMENT OF A FUNNEL FOR SHIPS 63-64 FOR THE BRO--ETC(U)
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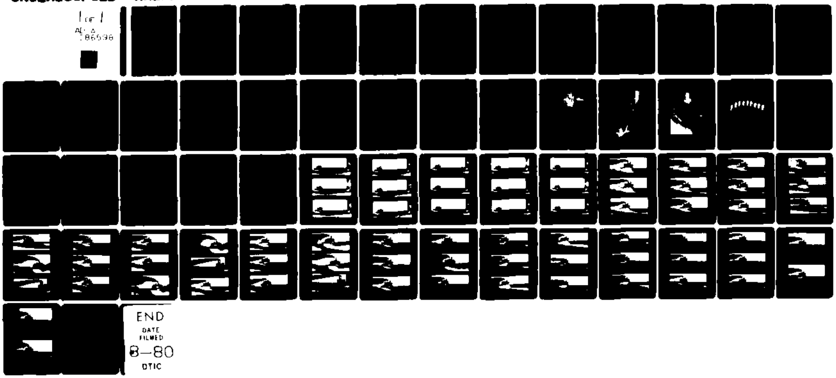

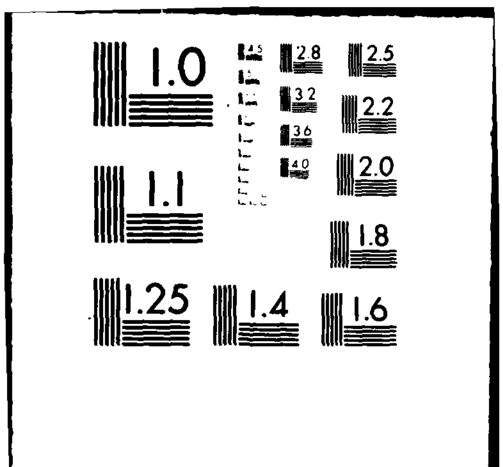

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Aerodynamics Technical Memorandum 317

WIND TUNNEL DEVELOPMENT OF A FUNNEL FOR SHIPS 63-64 FOR THE BROKEN HILL PROPRIETARY COMPANY LIMITED

T.H. TRIMBLE

Approved for Public Release.

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SUMMARY

The effectiveness of different configurations of funnel for SHIPS 63-64 was compared in a low speed wind tunnel investigation, at two engine power settings representing operations at light and full draft displacements.

The recommended configuration combined an elliptic envelope, or funnel casing, with a horizontal crown at a height of 6 metres above the compass bridge deckhead, enclosing the main gas turbine exhaust pipe which extended 1½ metres above the crown of the casing.

POSTAL ADDRESS: Chief Superintendent, Aeronautical Research Laboratories, P.O. Box 4331, Melbourne, Victoria, 3001, Australia.

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16. ABSTRACT:

The effectiveness of different configurations of funnel for SHIPS 63-64 was compared in a low speed wind tunnel investigation, at two engine power settings representing operations at light and full draft displacements.

The recommended configuration combined an elliptic envelope, or funnel casing, with the horizontal crown at a height of 6 metres above the compass bridge deckhead, enclosing the main gas turbine exhaust pipe which extended 1½ metres above the crown of the casing.

AUTHOR'S STATEMENT

This note formally describes, and records the results of, an investigation made in the 2.74 metre by 2.13 metre low speed wind tunnel between April 1974 and April 1976, which information was communicated in full to the Broken Hill Proprietary Company Limited in December 1976.

CONTENTS

NOTATION

D	diameter of exhaust pipe (main gas-turbine)
K_B	$\frac{\Delta_\rho \, D \, g}{\rho_a \, V_R^2}$ buoyancy coefficient
K_V	$\frac{\rho_g \, v_g^2}{\rho_a \, V_R^2}$ momentum flux coefficient
V_R	relative windspeed, knots
V_S	ship's speed, knots
V_W	true (natural) wind speed, knots
g	acceleration due to gravity
ℓ	reference length
v_g	velocity of (exhaust) gas at outlet
θ	wind direction (true) w.r.t. stationary ship
θ_R	relative wind direction w.r.t. moving ship (yaw setting in tunnel)
ρ_a	density of air
ρ_g	density of (exhaust) gas
Δ_ρ	$\rho_a - \rho_g$
δh	g.t. exhaust pipe extension above funnel crown, m
ERVAIN	engine room ventilation air intake(s) (inflow)
ERVOUT	engine room ventilation air outlet (outflow)
GALAIN	galley, crew's quarters conditioning air intake (taken in)
GASTAIN	main gas turbine air intake (intakes) (taken in)
GASTOUT	main gas turbine air out (outflow) (exhaust)

Notes:

1. Funnel height is defined as the height of the envelope e.g. 4m, 5m, 6m.

2. All funnel heights are measured from the compass bridge deckhead.

3. Main gas turbine exhaust pipe extensions are measured from the crown of the funnel, e.g. a 5m funnel with a pipe extension of δh = 1m (which provides an overall height to outlet of 6m above the compass bridge deckhead).

4. All dimensions (lengths, speeds etc.) refer to full scale conditions unless specifically stated to be otherwise.

1. INTRODUCTION

In March 1974 the Broken Hill Proprietary Company Limited requested that flow studies be made of the engine installation of SHIP 63, of 43700 MDWT, then in design[1]. An order[2] for the investigation was placed on ARL in mid-1975 by which time construction of the models was well advanced.

This report describes wind tunnel investigations which were made in 1975-1976. The tests were aimed at developing a funnel design which would avoid contamination of the intakes for the main gas turbine (GASTAIN) the engine room ventilation (ERVAIN), the galley and crew's quarters ventilation (GALAIN). The test conditions represented steady natural winds from various directions up to a strength of 25 knots (from ahead to abeam) and of 30 knots (from abeam to astern) for two ship's drafts (light and full).

Since no particular funnel shape was preferred by the client, a range of models (Figure 4), based on sketches supplied, was prepared for investigation. These g.r.p. shells varied in height, cross-section, taper and external width. Only the base length measured at the level of the compass bridge deck, and the slope of the forward and rear edges, were identical for all models. Details are shown in Figure 5a,b,c.

2. MODELS

A solid timber model (Figures 1,2,3) of the ship's hull above the light draft waterline was made in ARL to a scale of 1:100 from drawings[3] próvided. The lower slab of the hull was made removable so that the heavy draft displacement of the ship could be represented.

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1. a. Meeting and discussion in ARL

   b. Letter from BHP Coy. Ltd. 17/4/74

2. Order no. B20555 13/6/75

3. Lines plan, MODEL No. 4699

   Drawing No. M.4699-10

Details[4] of deck-works and superstructure, masts, inlets and outlets considered necessary for reproduction in the model were extracted and/or provided from various sources as required.

The model contained ducting through which were represented separately

a. main gas turbine airflow in,

b. main gas turbine airflow out (funnel pipe),

c. engine room ventilation airflow in,

d. engine room ventilation airflow out,

e. galley/crew's quarters ventilation airflow in.

For convenience from hereon a separate acronym will describe both the function and the source of each of the above, as defined in the NOTATION.

3. MODELLING

The initial path of the exhaust plume is dependent on uptake diameter, gravitational acceleration and the velocity, density and viscosity of both free stream and the efflux. In order to correctly model plume behaviour dimensional analysis shows that the following three dimensionless combinations of variables should be the same for the model as for the full scale ship.

Reynolds number $R = \rho V_R \ell / \mu$

Momentum flux coefficient $K_V = \rho_g \, v_g^2 / \rho_a \, V_R^2$

Buoyancy coefficient $K_B = \Delta\rho \, D \, g / \rho_a \, V_R^2$

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4. a. Ship 63, contract general arrangement, Plan 63/CA1

b. Ship 63, general arrangement, Plan No. B.101

c. Sketch of superstructure, unnumbered

d. Sketch of funnel, unnumbered

e. Sketch (2) of foremast, unnumbered

f. Machinery arrangement drawings, YARD (AUSTRALIA) Y2118/E1.

In practice it is not generally possible to maintain the correct Reynolds number because of the small model scale. But experience has shown that this requirement may be safely relaxed as the airflow over bluff bodies (such as ships) and sharp-edged superstructures shows little or no dependence on Reynolds number. Although scale effects can occur locally, for example where there are curved surfaces in the free stream, they do not apply in the present instance because the funnel stands within the turbulent airflow enveloping the ship.

For most of this investigation no attempt was made to satisfy the buoyancy scaling coefficient since buoyancy of the exhaust plume has only a small effect on the path of the plume

a. unless the exhaust escapes beyond the turbulent air about the ship. This is likely to occur only when the efflux momentum is reasonably high and/ or the funnel is sufficiently tall.

b. when the efflux momentum is low so that the exhaust flow begins to break up close to its outlet, or becomes entrained in the turbulent wake of the funnel casing with consequent rapid cooling due to mixing.

For these tests the turbulence boundary is near the ship's masthead, and hence above any likely funnel outlet, and the maximum natural wind strength investigated from ahead (25 knots) when combined with either operating condition of the ship produces a fairly low value of K_V, the momentum flux coefficient. Thus scaling requirements were reduced to achieving similarity of geometry and momenta of the flows; in a few selected cases values of the buoyancy and momentum parameters for the gas turbine exhaust (GASTOUT) were coincidentally correct. The exhaust plume from the model was made visible by a stream of vapourised oil carried in nitrogen or, in the few selected cases, helium. The former is often described as a "cold" plume.

The following information, based on design estimates, was provided for calculating the various flows through the model.

a. SHIP'S SPEED:

Light draft (8m)	16.4 knots
Full draft (12,4m)	14.5 knots

b. MAIN GAS TURBINES:

Air flow in 175086 kg/h

Temperature 26.7°C

Duct diameter (assumed) 2m (equiv.)

Gas flow out 177256 kg/h

Temperature (at regen'r outlet) 332°C

Average rel. dens. was taken as 0.5

Duct diameter (funnel) 2m

c. ENGINE ROOM VENTILATION AIR:

Air flow in 2 x 90000 m^3/h

Air flow out Assumed as above

* Outflow velocity 5,1 m/s

Temperature assumed normal

Duct diameter (assumed) 2 x 1,2m

* 1000 ft/min. later increased to 2000 ft/min.

d. GALLEY, CREW'S QUARTERS VENTILATION AIR:

Airflow in 18000 m^3/h

Temperature assumed normal

From the above information, and the data of Section 2, values of K_V and K_B for the main gas turbine exhaust and values of the relative wind strength and direction were calculated for the following conditions:

a. two ship's speeds, given by light and full draft operations,

b. natural wind strengths to 25 knots from true directions of ahead to abeam,

c. natural wind strengths to 30 knots from true directions of abeam to astern.

Momentum coefficients calculated for the ventilation flows (and not shown here) were related to those for the main exhaust.

Typical curves based on these calculations are shown in Figures 6-8. The general momentum curve of Figure 6 can be expanded into the more detailed form of Figure 7. Figures 7 and 8 are for the light draft displacement only, about which most of this investigation was made.

Small variations from the foregoing data, about equivalent to a knot of relative wind speed at full scale, a few percent of gas mass flows and several degrees of bearing at the larger yaw settings in the tunnel were shown to be not significant.

4. PRIMARY INVESTIGATION - LIGHT DRAFT CONDITION

The model was mounted on the turntable of a false floor in the low speed wind tunnel. Except when visualising the flow over the ship with cotton tufts or smoke streams, or when both K_V and K_B were coincidentally correct, the wind speed was 6.1 m/s (20 ft/sec). This figure was chosen for convenience because of the size of the model in relation to the capacities of available suction and smoke-generating devices.

The relative bulk of the ship above water in light draft, compared with that at full draft, suggested that the light draft condition would cause more disturbance of air and larger wakes with greater risk of contamination from the exhaust. Thus most of the tests were carried out for this condition.

For a given ship's speed the lowest values of K_V occur for the maximum relative wind velocities i.e. with the wind from ahead. Also previous tests have shown that the effectiveness of the funnel is often less when the relative wind lies 10° - 20° off the bow. These cases therefore received most attention.

4.1 Flow visualisation

The lines of flow above the ship's centreline in a headwind are shown by smoke stream in Figures 9-14. Complementary to these are Figures 15-23 which show the flight of a cotton tuft in the stream. It should be noted when viewing these figures that both forms of flow visualisation suffer disadvantages. The smoke disappears in the wake of the superstructure due to diffusion and inadequate illumination and the tuft does not accurately define the flow direction because of the effect of gravity. Nevertheless, the indication of flow direction, reversed flow and flow separation and the level of (and changes in) turbulence is good to excellent. In each of these figures the funnel is represented by a pipe of 4m height. Figures 11-12, 21-23 show clearly how the flow over, above and behind the superstructure is disturbed, and how ineffective a funnel of that height would be. For added interest, the increased effectiveness of a pipe extended to 7m and exhausting into less turbulent air is shown in Figures 24-26.

The photographs provide time-averaged displays of the funnel plumes. Because the boundaries often suffer lack of definition, in many cases the lower boundary and other detail of the plume have been illustrated with dashed lines.

For more detailed tuft studies of the flow the following comments are provided, without photographic illustration. Over the superstructure, and extending laterally to about the two-thirds beam, the top of the turbulent region in winds from ahead ($\theta_R = \pm 10^o$) is about 2-3 metres above the top of the mast. Thus the top of any funnel investigated (envelope or exhaust pipe) is enveloped in turbulent flow. There was, however, no clear indication from the tufts that much engine room ventilation exhaust (ERVOUT) from the rear of the funnel would be drawn into the main gas turbine intakes (GASTAIN). Possibly this was because the tuft material was too heavy, or stiffer than necessary for this purpose, although the wake from the gas turbine intakes housing was clearly shown.

In general terms the strong downwash behind the superstructure tended to ensure that any flow which fell below the level of the compass bridge deckhead before reaching the stern of the ship was likely to be entrained into the wake of the superstructure in relative winds from ahead, the entrainment lessening with reducing relative wind velocity.

4.2 Development of funnel

In developing a funnel to meet the stated requirements the following variables were examined:

Section (definition): fat, thin, flat, elliptic (see Figure 5)

Pipe extension (δh): up to 1½m above envelope

Crown: open, closed

Funnel (envelope) height: 4m, 5m, 6m.

4.2.1 Open Crown: (Fat and thin funnels only). This feature was examined because of an understanding in early discussions that the funnel envelope could be a plenum open from a level as low as the compass bridge deck. Funnels of 4m, 5m and 6m height were tested in winds from ahead. ERVOUT exhausted into the plenum helped to clear exhaust from the crown area. The 4m height was quite unacceptable. There was a slight gain in effectiveness in all cases when the pipe was extended 1m, with little to choose between the 5m and 6m funnels. None was considered satisfactory at $\theta_R = 0^o$, which implied that all would be worse with the relative wind a few degrees off the bow. Although the results are only of passing interest in view of the current intention that the funnel will be crown-plated the effect of the open crown is illustrated in Figures 27-32 (for the fat and the thin envelopes only).

4.2.2 Funnel height - 4 metres

Initially, visualisation studies of the flow over the superstructure with smoke stream and tuft had indicated that a funnel height in excess of 4m would be needed. Indeed, this was proved in tests with

the thin (only) 4m funnel which was examined with an open crown and with a closed crown, both with and without extended pipe. All of these configurations were unsatisfactory. Exhaust was easily entrained into the wake and wasdrawn against the rear of the funnel, into the intakes and over the swimming pool, against the rear of the superstructure and over the poop deck. This situation persisted for θ_R up to 20^o plus; the funnel effectiveness was acceptable at (the test positions of) $\theta_R = 57^o$ and 147^o. Of course, at these latter angles the strengths of the relative winds (of 25 knots and 30 knots true) are reduced so that values of K_V are increased over those at $\theta_R = 0^o$; accordingly the effectiveness of the funnel is increased. The plume from the 4m funnel, in each case without exhausting ventilation air is shown in Figures 33-38. Figures 37-38 show that with a pipe extension of 1m (half one one diameter) a funnel envelope as short as 4m would be satisfactory in the given maximum wind conditions provided that the relative wind were 50^o or more off the bow.

4.2.3 Funnel height - 5 metres and 6 metres

Taller funnels, in heights of 5m and 6m, were then examined. The low effectiveness of the fat and the thin funnels in these heights, funnels which were open-crowned, has already been described in Section 4.2.1. Because the openness of the crowns of these funnel sections did not appear to be the reason for their unsatisfactory performance two other section shapes were investigated. One was parallel-sided (defined as 'flat') and the other elliptic. Both shapes were fitted with crown plates.

The flat section, which provided a slender envelope in the direction of motion, was briefly examined only in a height of 5m, as was also the effect of exhausted ventilation air through a relatively small slot set high in the rear wall (¼m below the rim). The escaping ventilation air was expected to provide a near-horizontal curtain or jet which would entrain, and hence carry away, that part of the main exhaust which was drawn deep into the wake about the funnel. However, increasing the exhaust speed of the ventilation air with this configuration of slot and funnel only worsened the situation and increased entrainment of the gas turbine exhaust into the wake. Moreover, without a trailing ramp from the rim of the funnel to delay the attachment of the GASTOUT plume to the jet, the path of the plume was drawn down close to the funnel with increased entrainment of exhaust into the funnel wake. Because of the poor performance of this funnel up to $\theta_R = 37^o$ the flat shape was discarded, and further investigation of the effect of ERVOUT on the exhaust plume was confined to lesser escape speeds.

The funnel of elliptic section proved to be more effective than any of the other funnels, particularly in the range of $\theta_R = 0^o$ to 20^o. Improvements which were small but nevertheless worthwhile were achieved by increasing the height of the envelope from 5m up to 6m and extending the pipe up to about 1¼m beyond the plane of the crown.

It was found possible to obtain almost equal effectiveness from this shape of envelope in the 5m-6m height range combined with different extensions of pipe, provided that the outlet was at a height of 7m-7½m.

In the elliptic funnels the top of the ERVOUT opening was 3/4-1m below the crown and the flow speed was correct (and see later). The gross size of the opening was approximately 3m times 3m (measured in the surface of the envelope); wire mesh represented the louvres which might be expected to constrain the flow through the full scale outlet. By operating the ERVOUT 'off' and 'on' it was shown clearly that the continuous charging of airspace behind the funnel with this waste air partially reduced the strength of the funnel wake and its power to entrain the main exhaust. More will be said about this later.

GASTOUT plumes from elliptic funnels of 5m and 6m are shown in Figures 39-46 and Figures 47-53 respectively. These plumes are all in the absence of ERVOUT. Several of the figures illustrate well the improvement to be gained by raising the outlet above the pocket of separated flow which exists on the crown and which is caused by the circumferential ridge (perhaps 0.1m or more high). By way of further illustration this effect is shown in Figures 54-55 in which the top of the fat 6m envelope is slightly raked; the crown plate is horizontal and the separation is strong behind the high front ridge and at a level where it is better placed to attack the exhaust plume from a low outlet more readily than from a high outlet.

Plumes from 6m funnels with ERVOUT operating are shown in Figures 56-58. An approximate comparison may be made between the plumes shown in Figure 48 (without ERVOUT) and Figure 56 (with over-sped ERVOUT) despite a slight difference in exhaust pipe extension; the plume was just slightly higher with ERVOUT operating and slightly less of it was drawn into the near wake of the funnel.

4.3 Conclusions

From the foregoing investigation it was concluded that the ship would be reasonably free from contamination by exhaust gas in natural winds up to 25 knots (30 knots from astern) at the operating speed for light draft; the intakes for the main gas turbine, the engine room ventilation, the galley and crew's quarters ventilation would be similarly free, all provided that

a. the funnel envelope extended to 6m (or more) above the compass deckhead,

b. the main gas turbine exhaust pipe protruded not less than 1m beyond the crown (preferred horizontal),

c. the waste engine room ventilation air was exhausted through an opening in the rear wall of the funnel envelope. The top of this opening should be about 1m below the crown,

d. the funnel envelope should be elliptic in section; as investigated it was tapered in side profile only.

NOTE: These conclusions in the form of recommendations were passed to the client verbally, with the added information that small variations to meet the designer's preferences, or for other reasons of taste or company policy, would be acceptable and would be unlikely to alter the conclusions significantly. Since the plume had been modelled only in momentum, it is possible that the predictions are slightly pessimistic and that the buoyancy inherent in the actual plume would provide slightly better results at full scale.

5. FURTHER INVESTIGATION - FULL DRAFT CONDITION

The model was converted to represent the full draft condition of the hull. Further extensive studies made with a probing tuft confirmed that no significantly different flow patterns existed over the superstructure of this configuration.

On the basis of an elliptic funnel envelope of height 6m, with main gas turbine pipe protruding 1½m above the horizontal crown, contained inside a circumferential ridge plate about 0.1m high, investigations were made to extend the results previously obtained. Separately examined in detail were the effects of relative winds at small angles off the bow, of varying the ERVOUT escape speed, of lessening relative wind speed (and hence increasing K_V), and of simultaneously correct scaling of momentum and buoyancy in the plume. The ERVOUT opening in the rear of the funnel was re-made to provide the correctly scaled quantity/speed flow.

5.1 Angle of relative wind

The effect of the relative wind moving through 20 degrees off the starboard bow is shown in Figures 59-63. The natural wind strength represented was 25 knots, ship's speed 14½ knots, and ERVOUT escape speed 5.1m/s (1000 ft/min). At $\theta_R = 0^o, 5^o$ as far as could be seen GASTOUT cleared all intakes, superstructure and poop deck although it drew closer to the deck at $\theta_R = 5^o$. At $\theta_R = 10^o$ occasional traces were noticed in the leeward corner and against the rear face of the superstructure. At $\theta_R = 15^o$ the situation was slightly improved and at $\theta_R = 20^o$ all intakes and superstructure were untouched, with the lowest and most forward of the entrained plume well above and half way back along the poop deck. It was thus shown that with the relative wind 5^o-10^o off the bow the likelihood of exhaust contamination of the

rear superstructure and deck would be greatest, but even so in that sector of apparent wind the GASTAINS and ERVAINS would be clear.

5.2 Escape speed of ERVOUT

The escape speed of ERVOUT was varied by reducing the depth of the opening. In each instance the top of the opening remained at 1m below the crown. The flow was visualised with smoke and there was no GASTOUT flow at all. For V_W = 25 knots at $\theta_R = 0^o$. Figures 64-66 representing escape speeds of 5.1, 10.2 and 20.4 m/s showed that some proportion of the ERVOUT was entrained and drawn into the GASTAIN. It was not possible to do more than make a coarse estimate of this quantity which appeared to vary with escape speed. At 5.1 m/s some traces were seen against the superstructure at deck level; at 10.2 m/s this exhaust appeared to fall to only half superstructure height; at 20.4 m/s it did not fall below the level of D deck (navigating bridge). Only at 5.1 m/s did there appear to be any entrainment back into ERVAIN.

5.3 Effect of reduced relative wind speed

For a constant engine power setting (and hence ship's speed) a fall in the strength of the natural wind provides reduced V_R and hence increased K_V. Then the improved effectiveness of the funnel reduces the possibility of contamination from GASTOUT, and reduces the quantity of ERVOUT entrained in the wake and likewise swallowed by GASTAIN. Figures 67-69, representing V_W = 25,20,15 knots respectively at $\theta_R = 0^o$, are shown without re-touching for comparison of the degree of entrainment of both GASTOUT and ERVOUT in the funnel wake. In each case ERVOUT escape speed was 10.2 m/s and with reducing V_W (and hence V_R) the two exhaust streams appeared more distinctly individual. At V_W = 15 knots it was possible to observe clearly the separated and reversed wake rotating beside the funnel and up against the GASTAIN - a wake made visible because of the entrained ERVOUT smoke. The camera has stilled the movement which is clearest in Figure 69 (and detectable in Figures 64-66 also) wherein the image can be seen by the careful observer. By way of contrast, for the same speeds (V_W or V_R) the appearance of the GASTOUT plume alone (in the complete absence of ERVOUT) is shown in Figures 70-72. When ERVOUT was present the GASTOUT plumes of Figures 71-72 were lowered only slightly, as shown further in Figures 73-74.

To what extent the GASTOUT plume is affected (i.e. in height,entrainment) by the ERVOUT flow depends upon the pressure field in the vicinity of, and downstream of, the funnel. For constant engine operating conditions, exhaust fans duty, and configuration of funnel build this will depend upon V_R (and θ_R, although interest wanes for other than small θ_R). For the configuration recommended from this

investigation the variation in effect with variation in V_R was small enough to be of secondary importance.

5.4 Effect of buoyancy (GASTOUT only)

To this point all reporting has been concerned with plumes scaled for momentum only. As stated earlier this degree of scaling is often adequate, and the consequent predictions then contain a small safety factor which generally favours the effectiveness of the full scale funnel. Furthermore, if the funnel outlet is well within the turbulence flow over the ship, model plumes scaled for momentum only (often described as 'cold') are expected to represent correctly those at full scale.

In the present case the outlet of the recommended funnel was close enough to the turbulence ceiling to require a final check with buoyancy properly scaled. Helium replaced nitrogen as the carrier of the vapourised oil and the plume was examined through $\Theta_R = 0^o$-30^o and $V_W = 25,20,15$ knots. Figures 75-78 may be compared directly with Figures 70, ,73,74. The mean paths of the buoyancy modelled GASTOUT plumes were elevated slightly above the equivalent 'cold' plumes and it is predicted that they will prove to be more representative of the full scale results. Similar improvements over 'cold' plumes were noted for cases for Θ_R other than 0^o but they were not recorded on film.

Careful examination of the results depicted in Figures 75-76 showed that the effect of ERVOUT on the buoyant GASTOUT plume was very slight and certainly less than on a cold GASTOUT plume.

5.5 Conclusions

Investigations made with the full draft configuration fitted with the recommended funnel (4.3) confirmed the earlier conclusions and recommendations for the light configuration. Furthermore it was shown that:

a. buoyancy inherent in the GASTOUT would slightly improve the effectiveness of the funnel in preventing contamination of the ship by exhaust gases,

b. some of the ERVOUT would almost certainly be entrained down to the base of the funnel, and thus enter the GASTAIN. It was unlikely that this could be easily prevented.

LIST OF FIGURES

LIGHT DRAFT	THE MODELS	ARL NEG. NO.
27	4m funnel; δh=o; thin, open crown, ERVOUT $\theta_R=0^\circ$; V_S=16.4 knots; V_W=25 knots	9868 - 105
28	4m funnel; δh=1; thin; open crown, ERVOUT $\theta_R=0^\circ$; V_S=16.4 knots; V_W=25 knots	-104
29	5m funnel; δh=1; fat; open crown; ERVOUT $\theta_R=0^\circ$; V_S=16.4 knots; V_W=25 knots	- 95
30	5m funnel; δh=1; thin; open crown; ERVOUT $\theta_R=0^\circ$; V_S=16.4 knots; V_W=25 knots	- 97
31	6m funnel; δh=1; fat; open crown; ERVOUT $\theta_R=0^\circ$; V_S=16.4 knots; V_W=25 knots	- 90
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36	4m funnel; δh=1; thin; crown plate $\theta_R=340^\circ$; V_S=16.4 knots; V_W=25 knots	- 45
37	4m funnel; δh=1; thin; crown plate $\theta_R=57^\circ$; V_S=16.4 knots; V_W=25 knots	- 79
38	4m funnel; δh=1; thin, crown plate $\theta_R=147^\circ$; V_S=16.4 knots; V_W=30 knots	- 78
	<u>5m, 6m FUNNELS</u>	
39	5m funnel; δh=1; elliptic; crown plate $\theta_R=0^\circ$; V_S=16.4 knots; V_W=25 knots	- 58
40	5m funnel; δh=2; elliptic; crown plate $\theta_R=0^\circ$; V_S=16.4 knots; V_W=25 knots	- 59
41	5m funnel; δh=1; elliptic; crown plate $\theta_R=350^\circ$; V_S=16.4 knots; V_W=25 knots	- 57
42	5m funnel; δh=2; elliptic; crown plate $\theta_R=350^\circ$; V_S=16.4 knots; V_W=25 knots	- 60
43	5m funnel; δh=1; elliptic; crown plate $\theta_R=340^\circ$; V_S=16.4 knots; V_W=25 knots	- 56
44	5m funnel; δh=½; elliptic; crown plate $\theta_R=57^\circ$; V_S=16.4 knots; V_W=25 knots	- 80
45	5m funnel; δh=1; elliptic; crown plate $\theta_R=57^\circ$; V_S=16.4 knots; V_W=25 knots	- 81

LIGHT DRAFT	THE MODELS	ARL NEG. NO.
46	5m funnel; $\delta h=1$; elliptic; crown plate $\theta_R=147^o$; $V_S=16.4$ knots; $V_W=30$ knots	9868 - 77
47	6m funnel; $\delta h=0$; elliptic; crown plate $\theta_R=0^o$; $V_S=16.4$ knots; $V_W=25$ knots	- 53
48	6m funnel; $\delta h=1$; elliptic; crown plate $\theta_R=0^o$; $V_S=16.4$ knots; $V_W=25$ knots	- 68
49	6m funnel; $\delta h=0$; elliptic; crown plate $\theta_R=350^o$; $V_S=16.4$ knots; $V_W=25$ knots	- 54
50	6m funnel; $\delta h=0$; elliptic; crown plate $\theta_R=340^o$; $V_S=16.4$ knots; $V_W=25$ knots	- 55
51	6m funnel; $\delta h=1$; elliptic; crown plate $\theta_R=37^o$; $V_S=16.4$ knots; $V_W=25$ knots	- 74
52	6m funnel; $\delta h=1$; elliptic; crown plate $\theta_R=57^o$; $V_S=16.4$ knots; $V_W=25$ knots	- 75
53	6m funnel; $\delta h=1$; elliptic; crown plate $\theta_R=147^o$; $V_S=16.4$ knots; $V_W=30$ knots	- 76
54	6m funnel; $\delta h=0$; fat; raked crown; hoz. crown plate $\theta_R=0^o$; $V_S=16.4$ knots; $V_W=25$ knots	- 92
55	6m funnel; $\delta h=1$; fat; raked crown; hoz. crown plate $\theta_R=0^o$; $V_S=16.4$ knots; $V_W=25$ knots	- 89
56	6m funnel; $\delta h=1\frac{1}{2}$; elliptic; crown plate $\theta_R=0^o$; ERVOUT; $V_S=16.4$ knots; $V_W=25$ knots	- 87
57	6m funnel; $\delta h=1\frac{1}{2}$; elliptic; crown plate $\theta_R=350^o$; ERVOUT; $V_S=16.4$ knots; $V_W=25$ knots	- 88
58	6m funnel; $\delta h=1\frac{1}{2}$; elliptic; crown plate $\theta_R=37^o$; ERVOUT; $V_S=16.4.$ knots; $V_W=25$ knots	- 86
FULL DRAFT	**ANGLE OF RELATIVE WIND**	
59	6m funnel; $\delta h=1\frac{1}{2}$; elliptic; crown plate $\theta_R=0^o$; ERVOUT; $V_S=14.5$ knots; $V_W=25$ knots	- 114
60	6m funnel; $\delta h=1\frac{1}{2}$; elliptic; crown plate $\theta_R=5^o$; ERVOUT: $V_S=14.5$ knots; $V_W=25$ knots	- 113
61	6m funnel; $\delta h=1\frac{1}{2}$; elliptic; crown plate $\theta_R=10^o$; ERVOUT: $V_S=14.5$ knots; $V_W=25$ knots	- 112
62	6m funnel; $\delta h=1\frac{1}{2}$; elliptic; crown plate $\theta_R=15^o$; ERVOUT: $V_S=14.5$ knots; $V_W=25$ knots	- 110
63	6m funnel; $\delta h=1\frac{1}{2}$; elliptic; crown plate $\theta_R=20^o$; ERVOUT: $V_S=14.5$ knots; $V_W=25$ knots	- 108

FULL DRAFT	E.R. VENTILATION EXHAUST	ARL NEG. NO.
64	6m funnel; NO GASTOUT: ERVOUT 5.1 m/s $\theta_R=0^\circ$; V_S=14.5 knots; V_W=25 knots	9868 - 115
65	6m funnel; NO GASTOUT: ERVOUT 10.2 m/s $\theta_R=0^\circ$; V_S=14.5 knots; V_W=25 knots	- 118
66	6m funnel; NO GASTOUT: ERVOUT 20.4 m/s $\theta_R=0^\circ$; V_S=14.5 knots; V_W=25 knots	- 119
	RELATIVE WIND SPEED	
67	6m funnel; $\delta h=1\frac{1}{2}$; elliptic; crown plate $\theta_R=0^\circ$; ERVOUT = 10.2 m/s; V_S=14.5 knots; V_W=25 knots	- 120
68	6m funnel; $\delta h=1\frac{1}{2}$; elliptic; crown plate $\theta_R=0^\circ$; ERVOUT = 10.2 m/s; V_S=14.5 knots; V_W=20 knots	- 121
69	6m funnel; $\delta h=1\frac{1}{2}$; elliptic; crown plate $\theta_R=0^\circ$; ERVOUT = 10.2 m/s; V_S=14.5 knots; V_W=15 knots	- 122
70	6m funnel; $\delta h=1\frac{1}{2}$; elliptic; crown plate $\theta_R=0^\circ$; V_S=14.5 knots; V_W=25 knots	- 127
71	6m funnel; $\delta h=1\frac{1}{2}$; elliptic; crown plate $\theta_R=0^\circ$; V_S=14.5 knots; V_W=20 knots	- 125
72	6m funnel; $\delta h=1\frac{1}{2}$; elliptic; crown plate $\theta_R=0^\circ$; V_S=14.5 knots; V_W=15 knots	- 123
73	6m funnel; $\delta h=1\frac{1}{2}$; elliptic; crown plate $\theta_R=0^\circ$; ERVOUT = 10.2 m/s; V_S=14.5 knots; V_W=20 knots	- 126
74	6m funnel; $\delta h=1\frac{1}{2}$;elliptic; crown plate $\theta_R=0^\circ$; ERVOUT = 10.2 m/s; V_S=14.5 knots; V_W=15 knots	- 124
	BUOYANCY	
75	6m funnel; $\delta h=1\frac{1}{2}$; elliptic; crown plate $\theta_R=0^\circ$; V_S=14.5 knots; V_W=25 knots	- 128
76	6m funnel; $\delta h=1\frac{1}{2}$; elliptic; crown plate $\theta_R=0^\circ$; ERVOUT = 10.2 m/s; V_S=14.5 knots; V_W=25 knots	- 129
77	6m funnel; $\delta h=1\frac{1}{2}$; elliptic; crown plate $\theta_R=0^\circ$; ERVOUT = 10.2 m/s; V_S=14.5 knots; V_W=20 knots	- 130
78	6m funnel; $\delta h=1\frac{1}{2}$; elliptic; crown plate $\theta_R=0^\circ$; ERVOUT = 10.2 m/s; V_S=14.5 knots; V_W= 15 knots	- 131

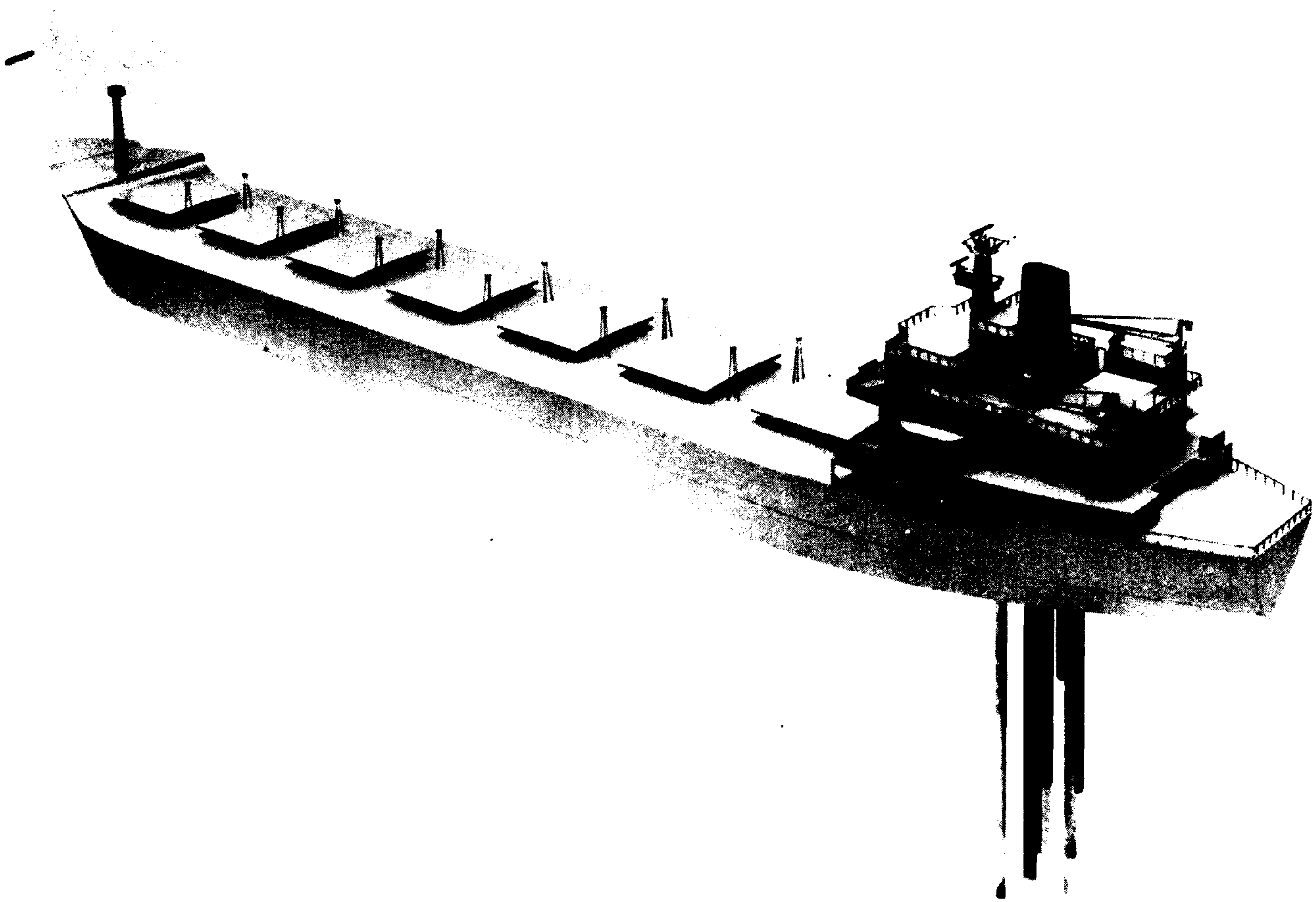


FIG. 1. NEG. NO. 9715-A

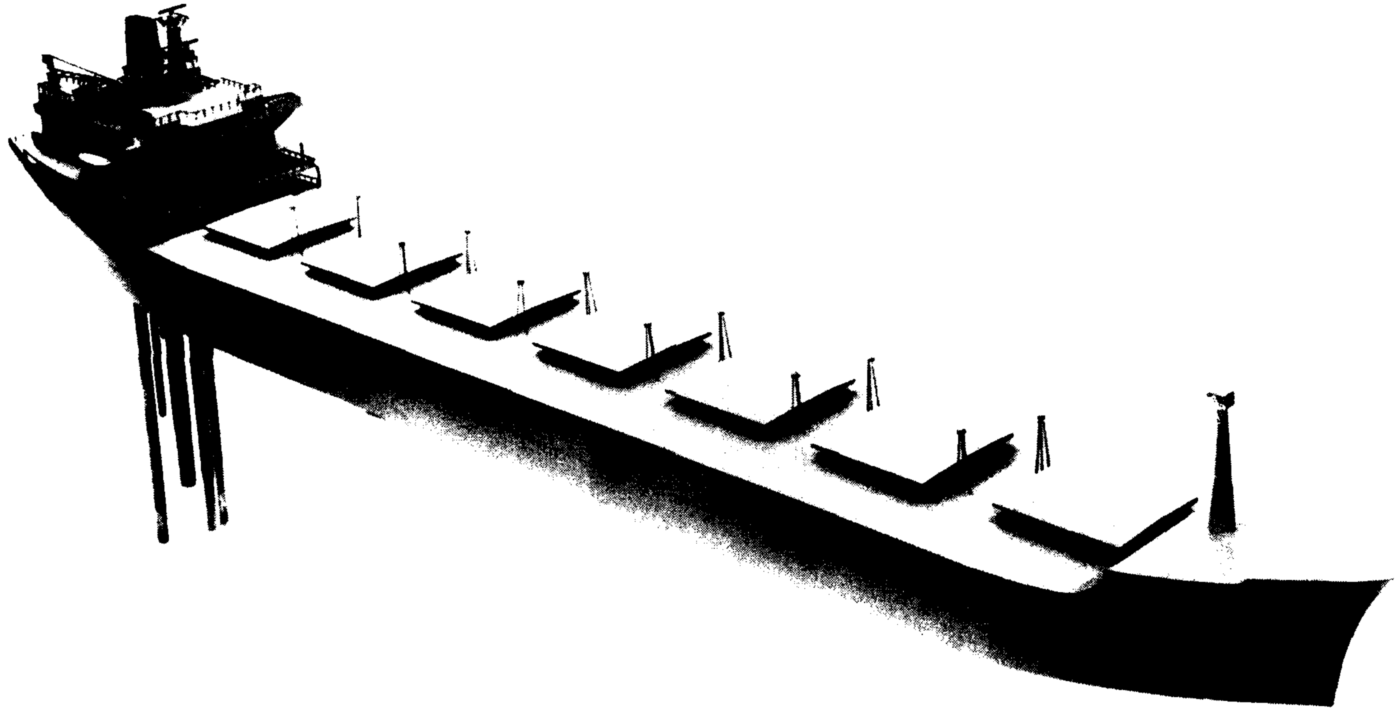


FIG. 2.

NEG. NO. 9715-B

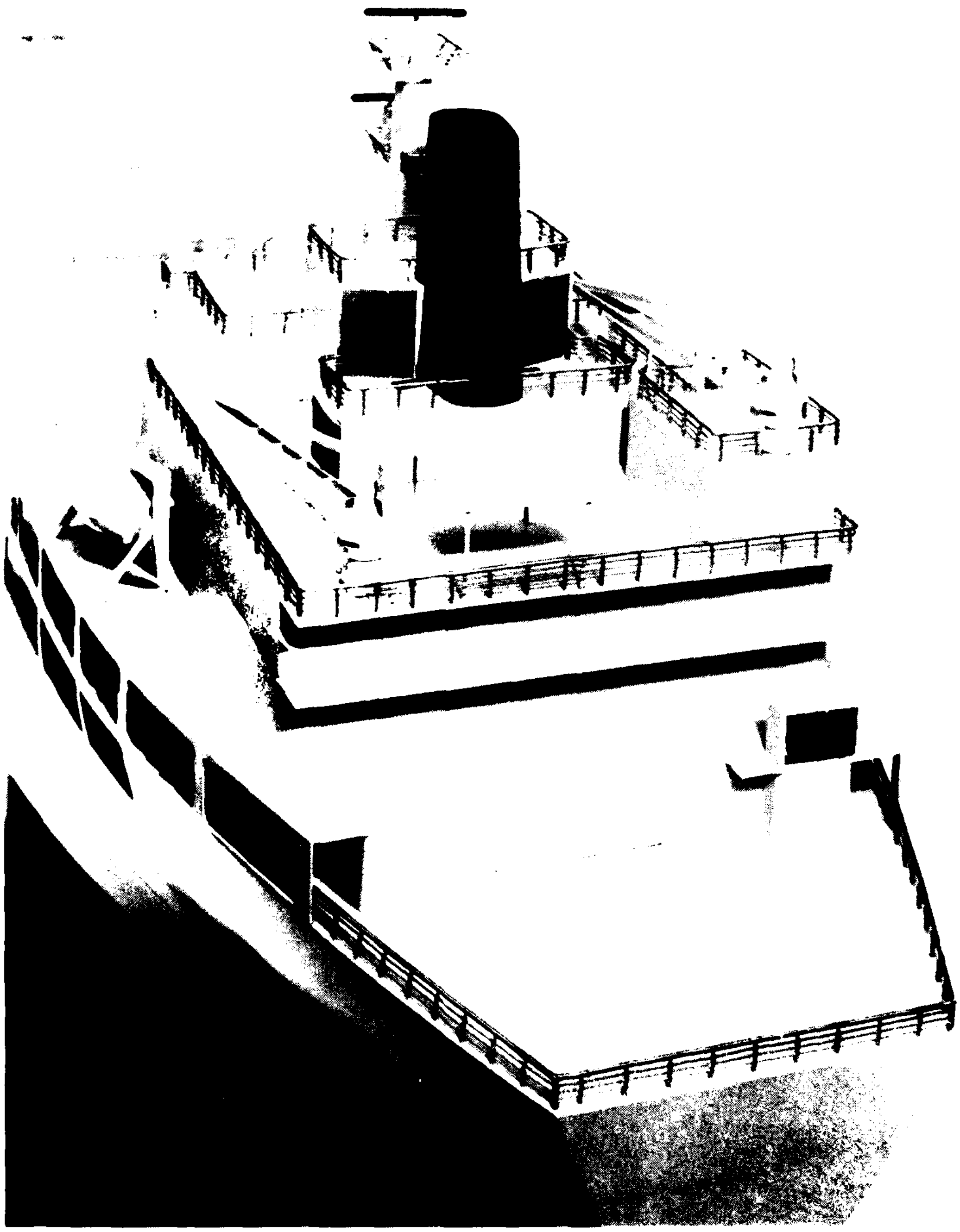


FIG. 3. NEG. NO. 9715-C

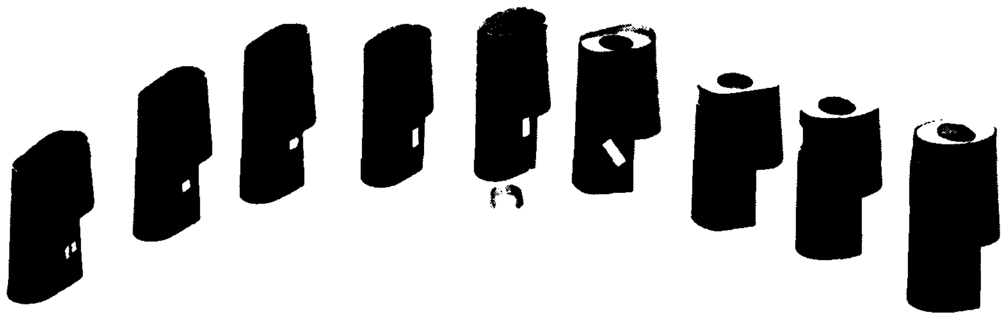


FIG. 4.

NEG. NO. 9913

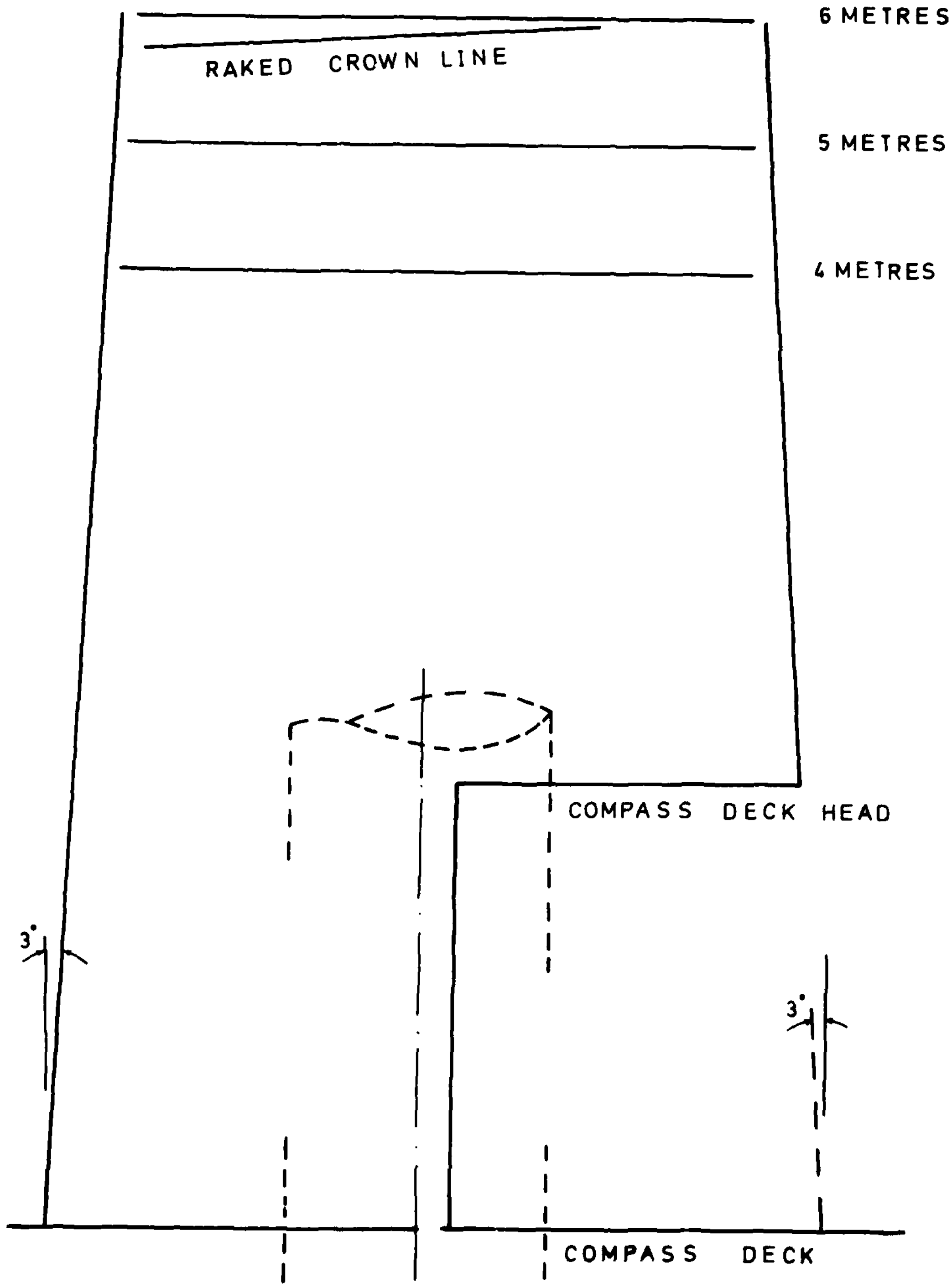
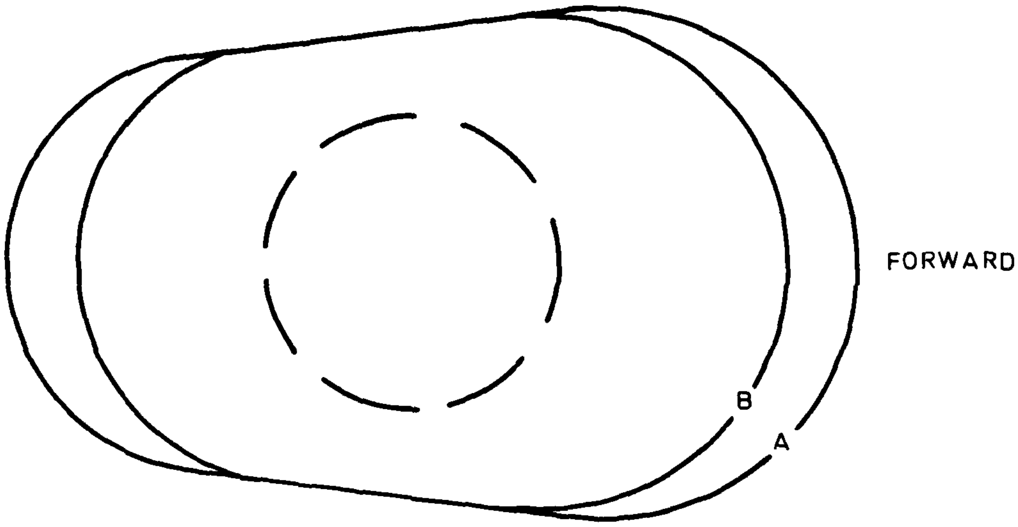
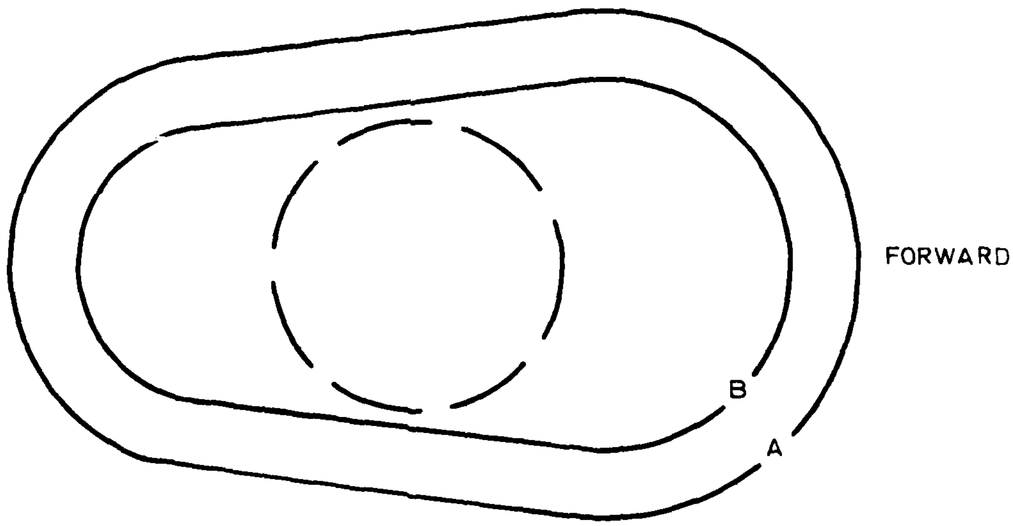


FIG.5(a) SIDE ELEVATION, ALL FUNNELS (scale 1 : 50)

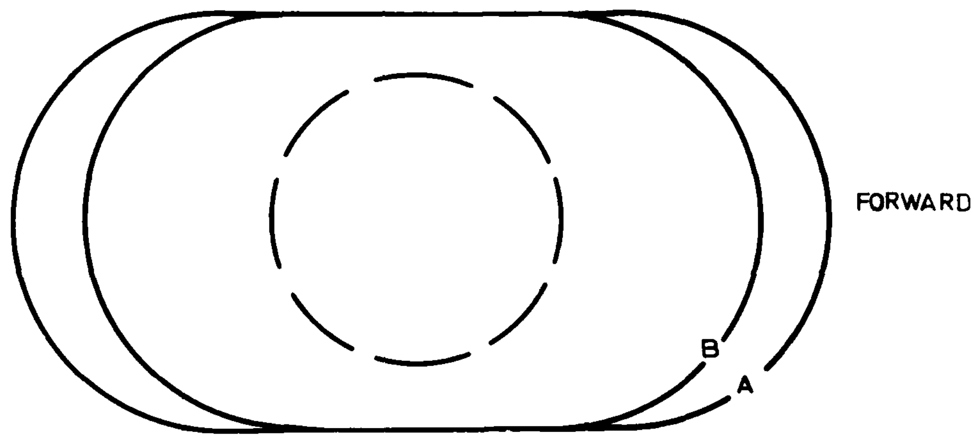


FAT SECTION

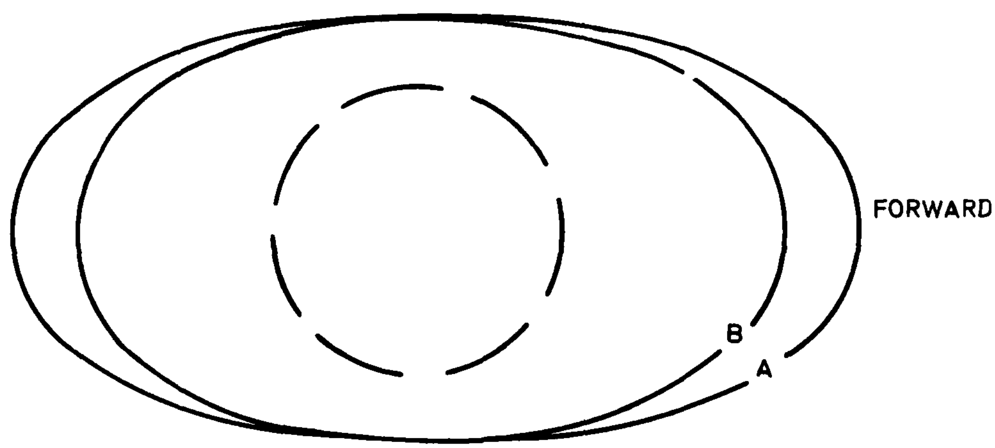


THIN SECTION

FIG.5(b) A - SECTION AT LEVEL OF COMPASS DECK
B - SECTION AT 6 METRE HEIGHT



FLAT SECTION



ELLIPTIC SECTION

FIG.5(c) A – SECTION AT LEVEL OF COMPASS DECK
B – SECTION AT 6 METRE HEIGHT

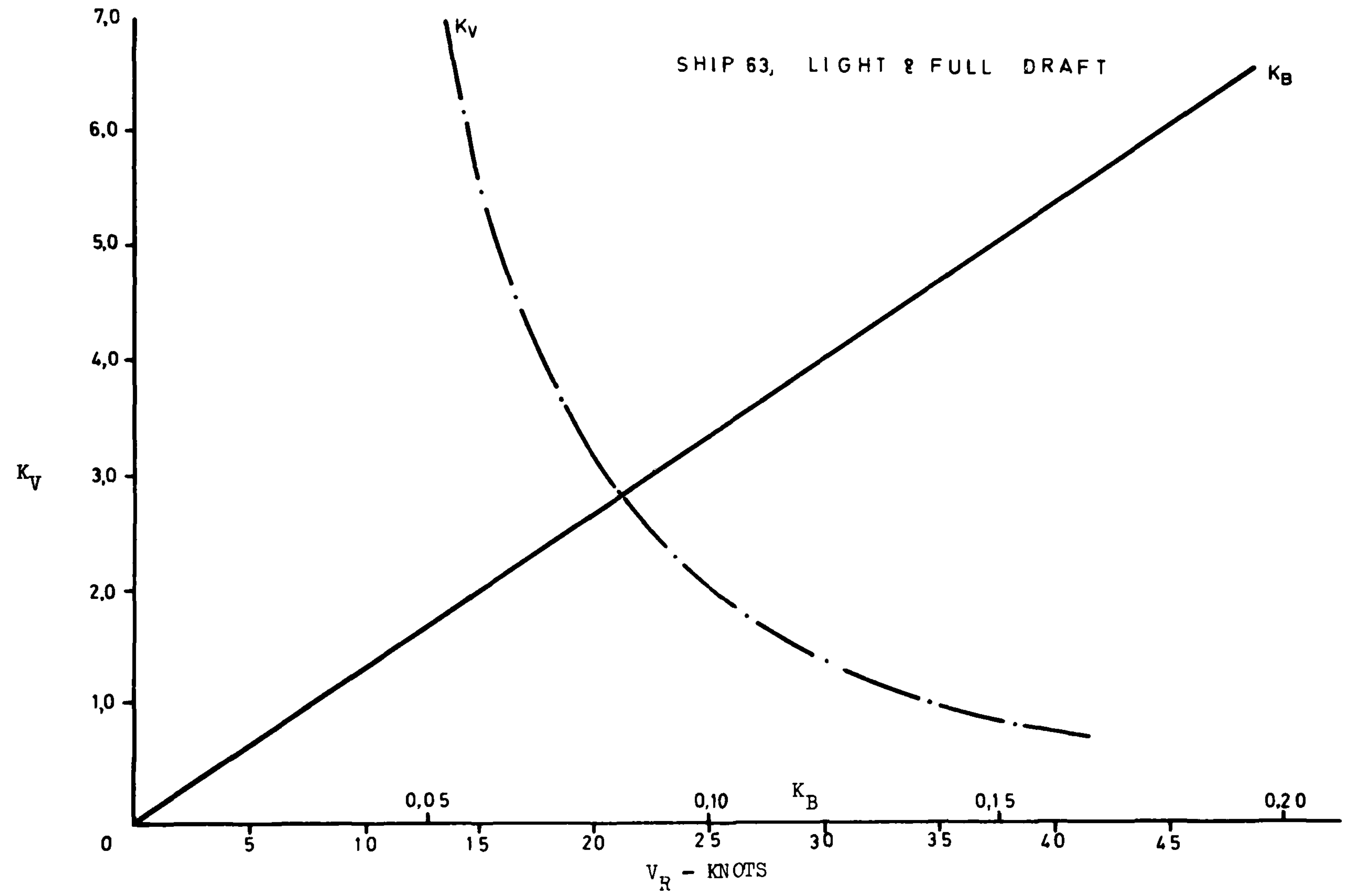


FIG.6 K_V vs K_B and V_R ---- GENERAL CURVES FROM DATA (SECTS 2 & 3)

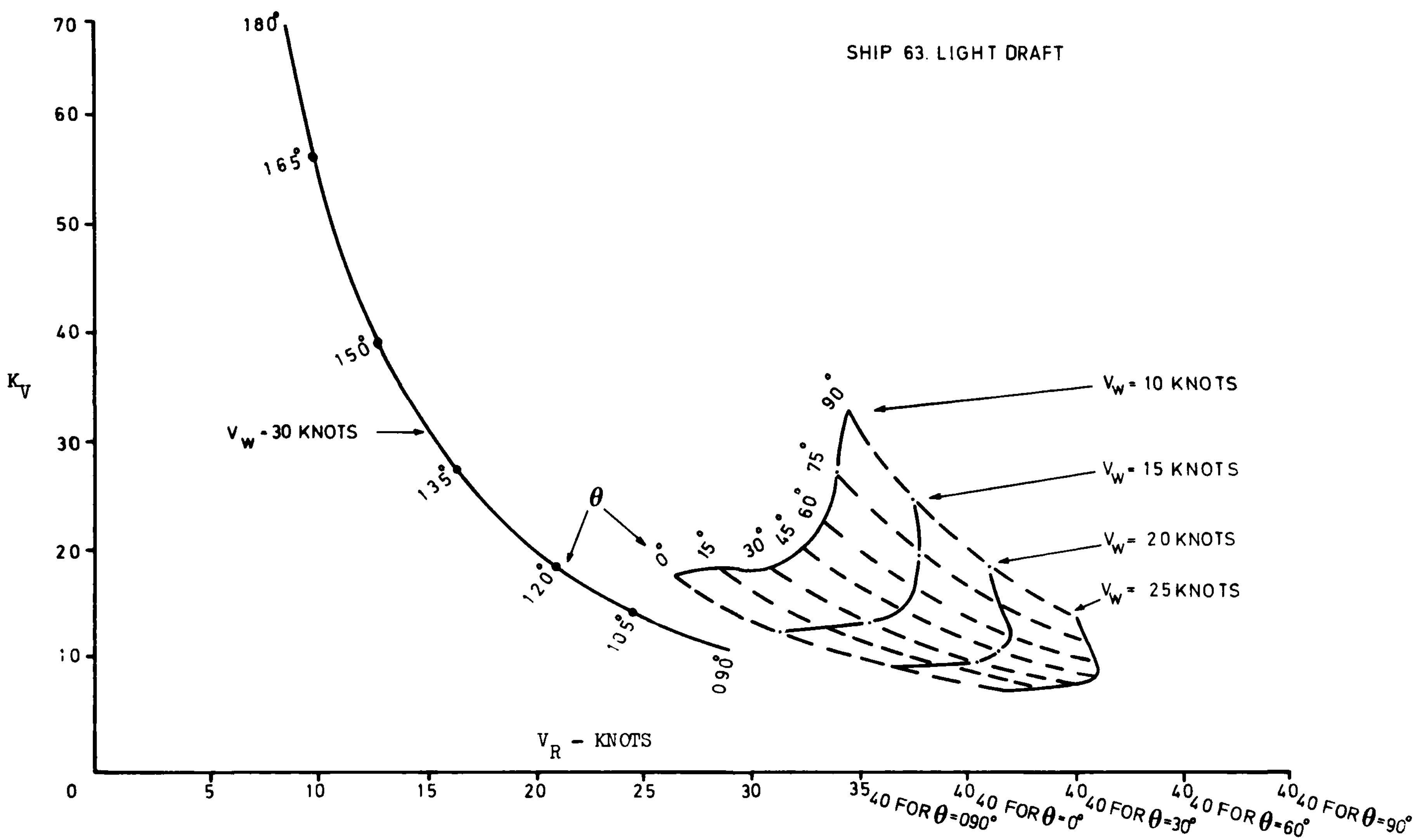


FIG.7 K_V vs V_R FOR TRUE WINDS FROM AHEAD TO ASTERN

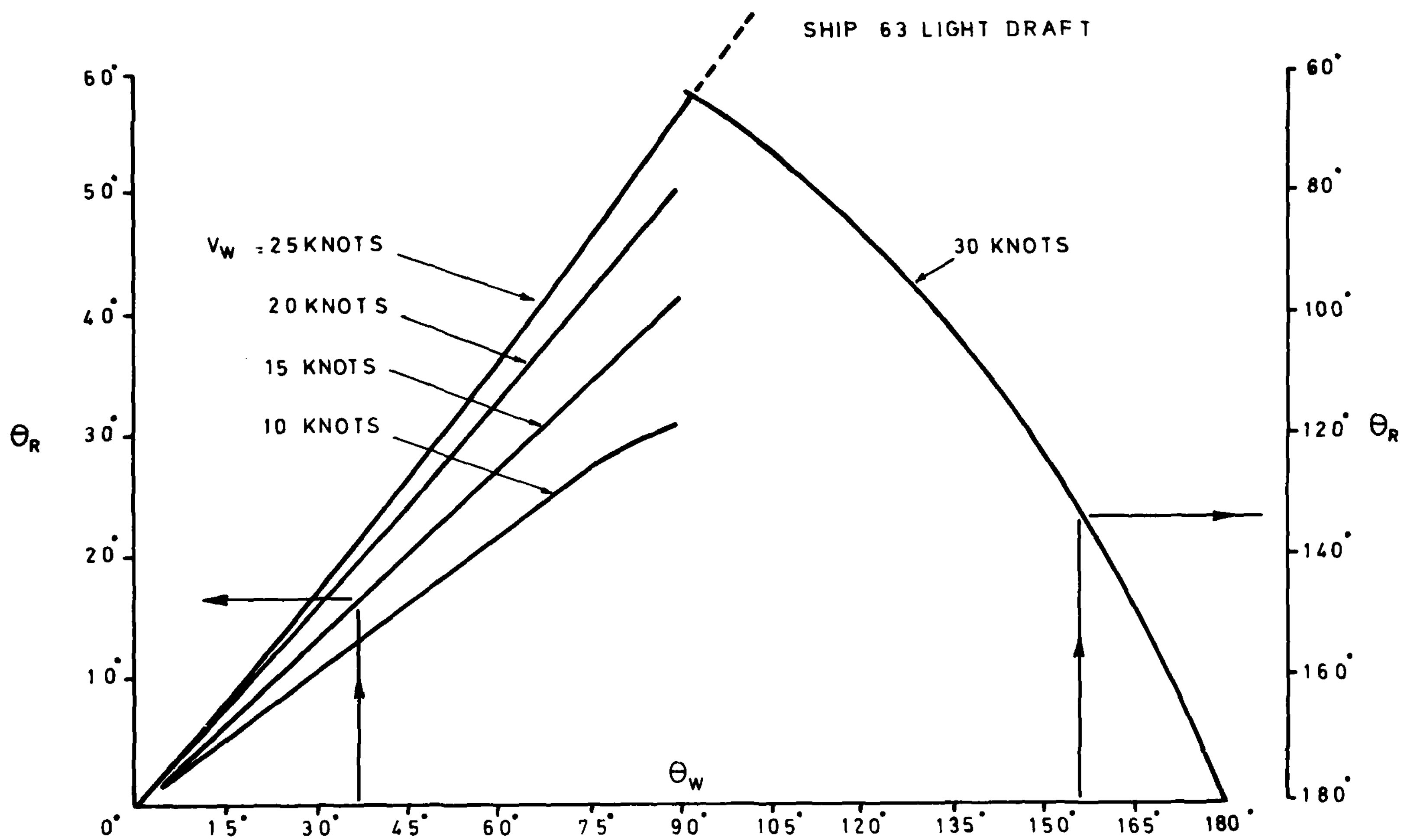


FIG.8 RELATIVE vs TRUE DIRECTION FOR (a) WINDS OF 10–25 KNOTS FROM AHEAD TO ABEAM
(b) WIND OF 30 KNOTS FROM ABEAM TO ASTERN

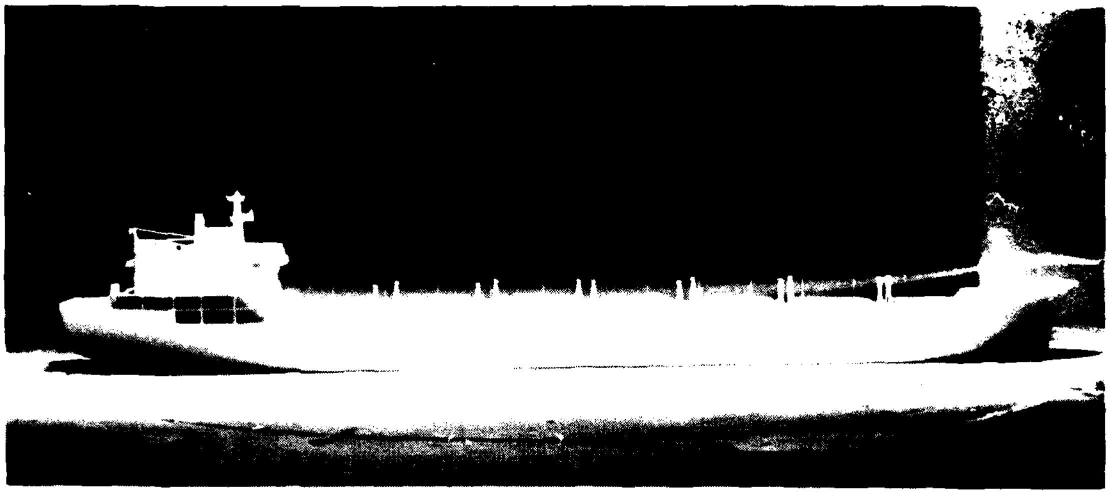


FIG. 9. NEG. NO. 9868-25

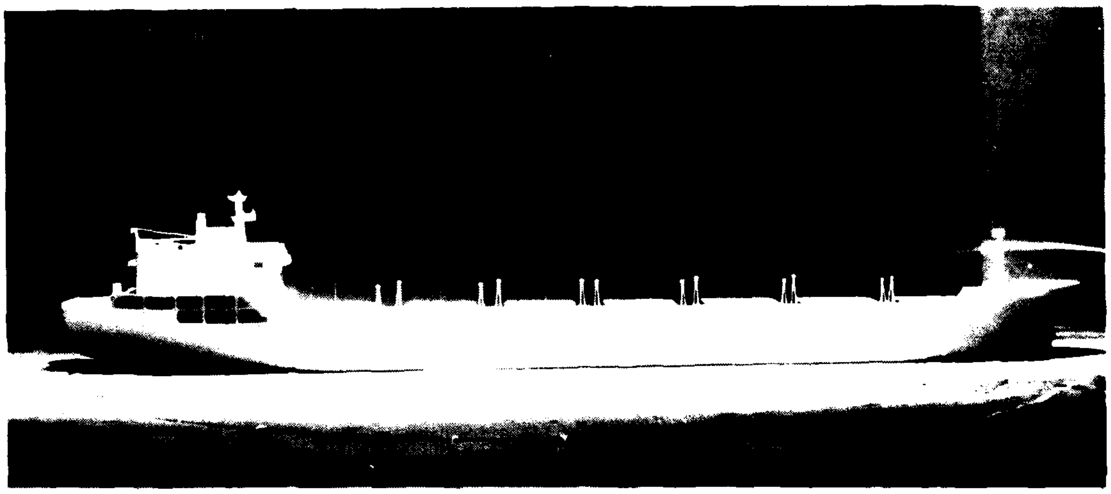


FIG. 10. NEG. NO. 9868-26

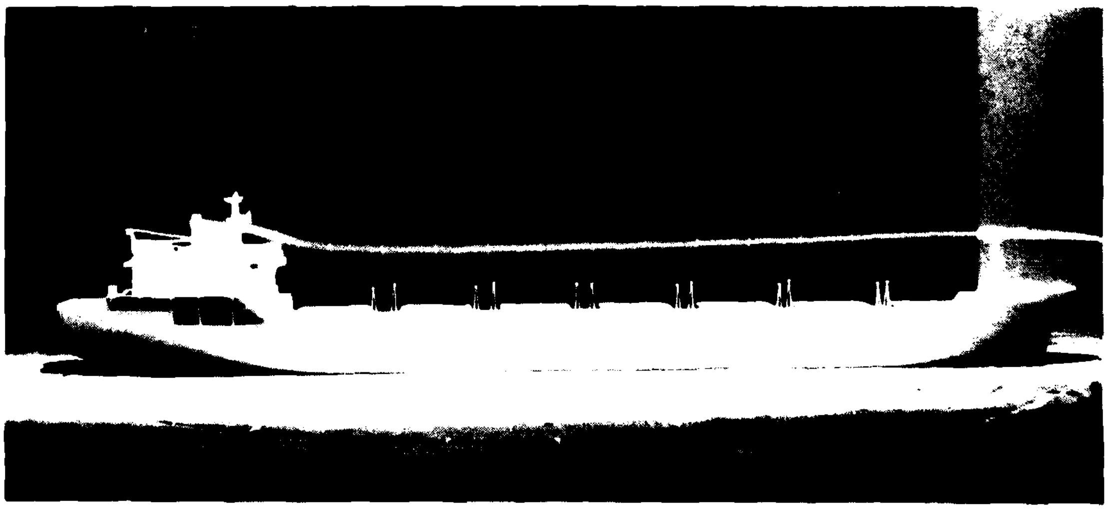


FIG. 11. NEG. NO. 9868-27

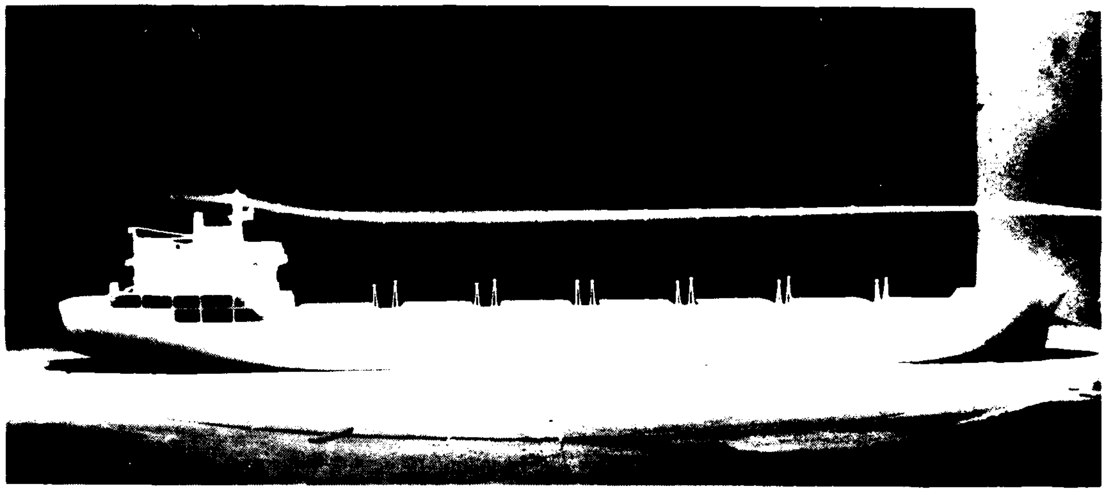


FIG. 12. NEG. NO. 9868-28

FIG. 13. NEG. NO. 9868-29

FIG. 14. NEG. NO. 9868-30

FIG. 15 NEG. NO. 9868-31

FIG. 16. NEG. NO. 9868-33

FIG. 17. NEG. NO. 9868-34

FIG. 18. NEG. NO. 9868-36

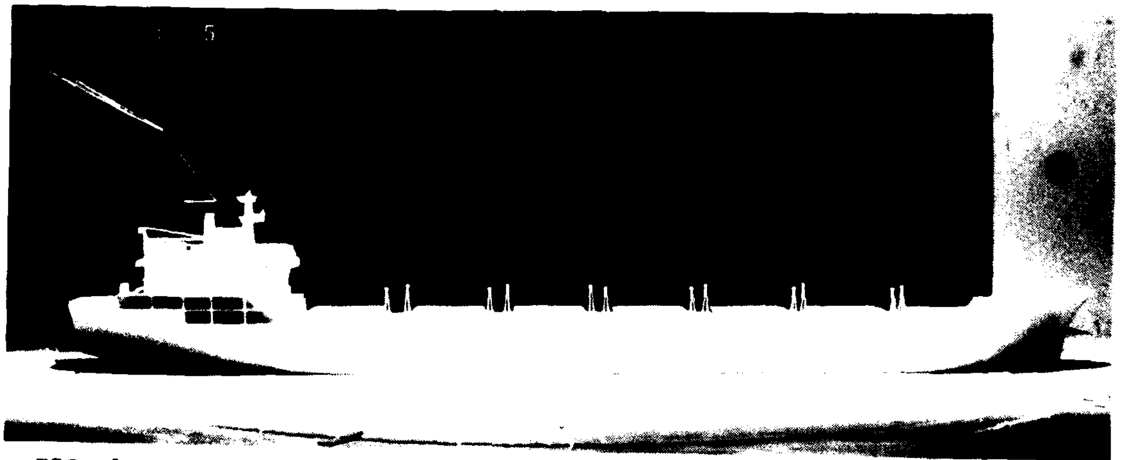


FIG. 19. NEG. NO. 9868-35

FIG. 20. NEG. NO. 9868-40

FIG. 21. NEG. NO. 9868-38

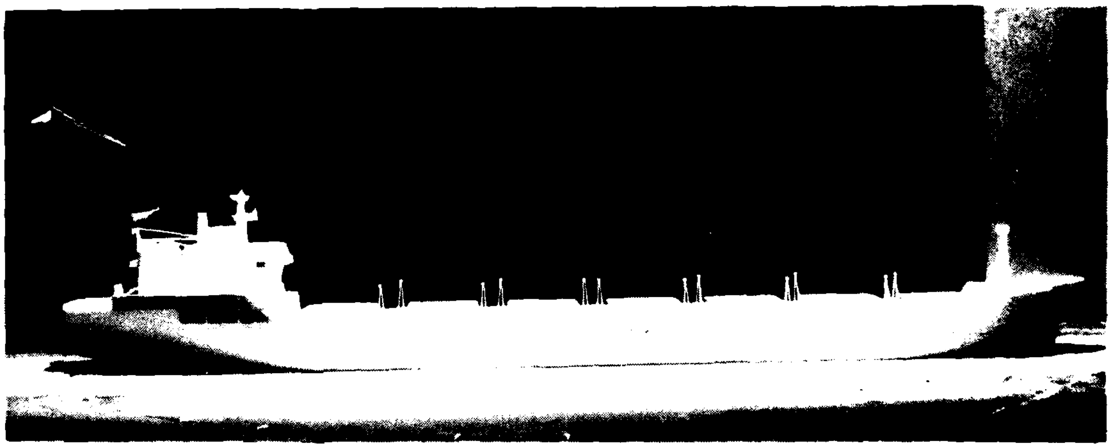


FIG. 22. NEG. NO. 9868-37

FIG. 23. NEG. NO. 9868-39

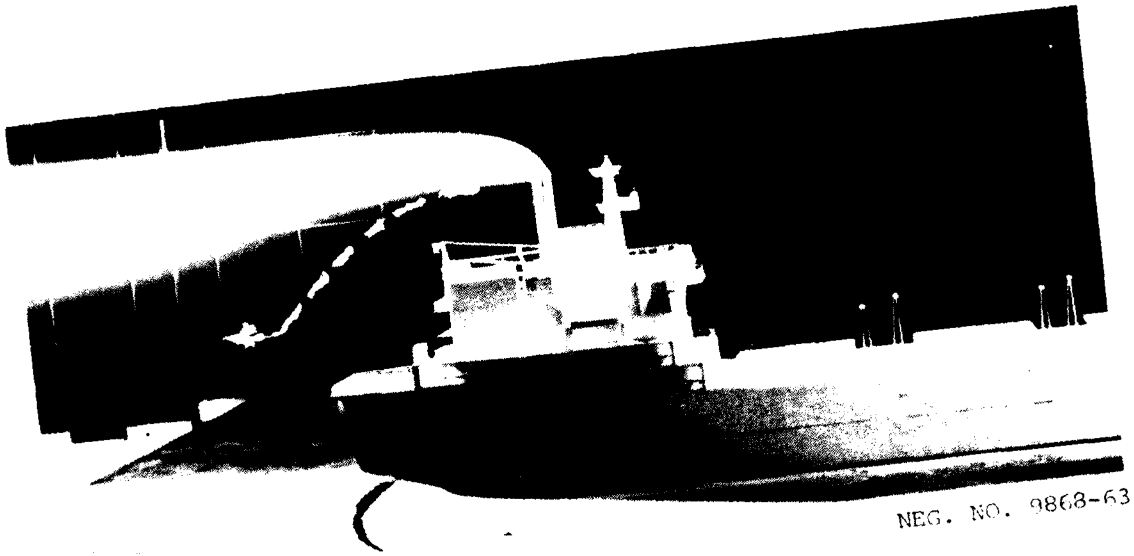


FIG. 24.

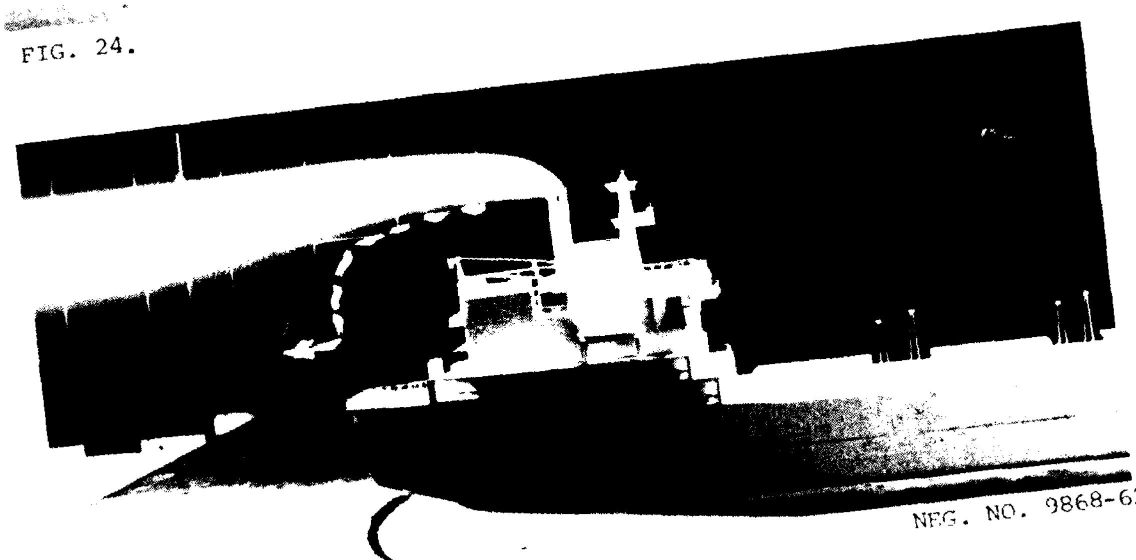


FIG. 25.

FIG. 26.

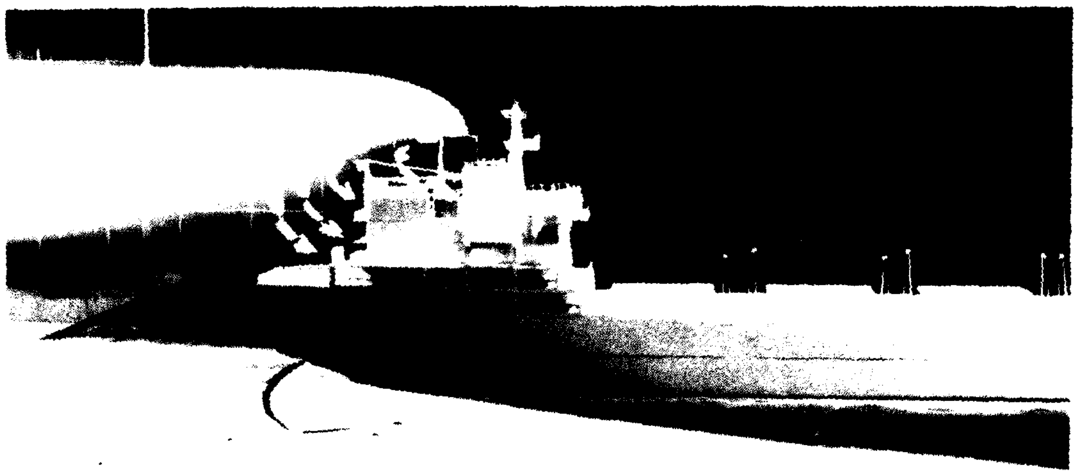


FIG. 27. NEG. NO. 9868-105

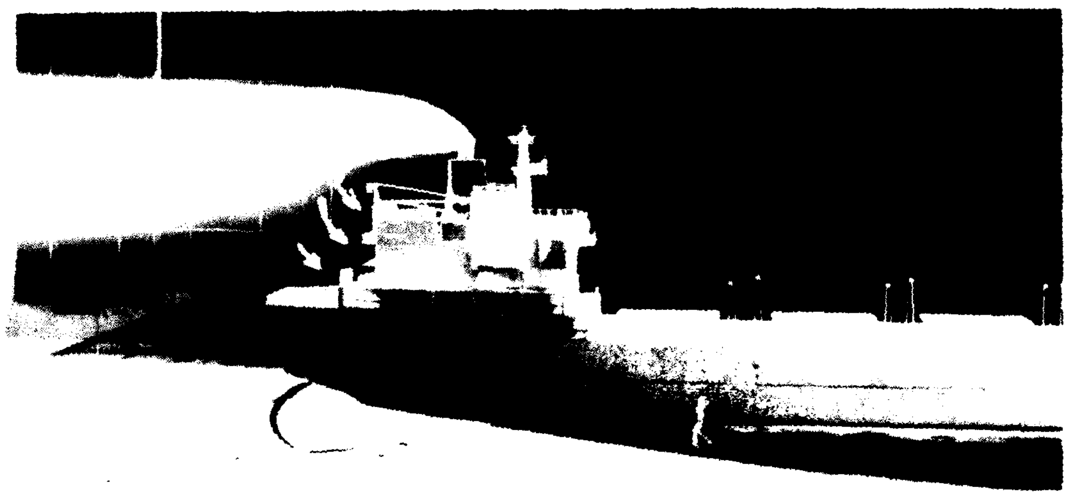


FIG. 28. NEG. NO. 9868-104

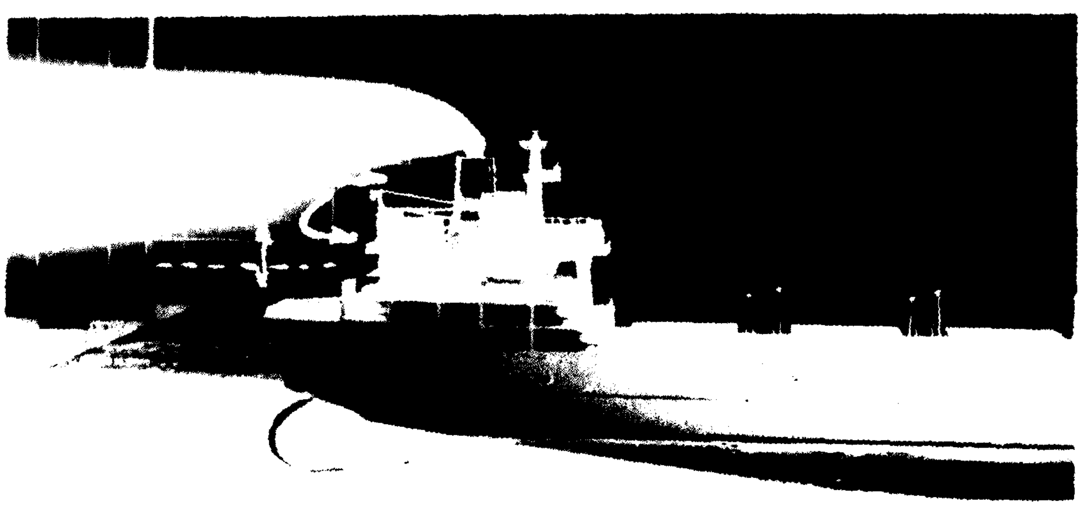
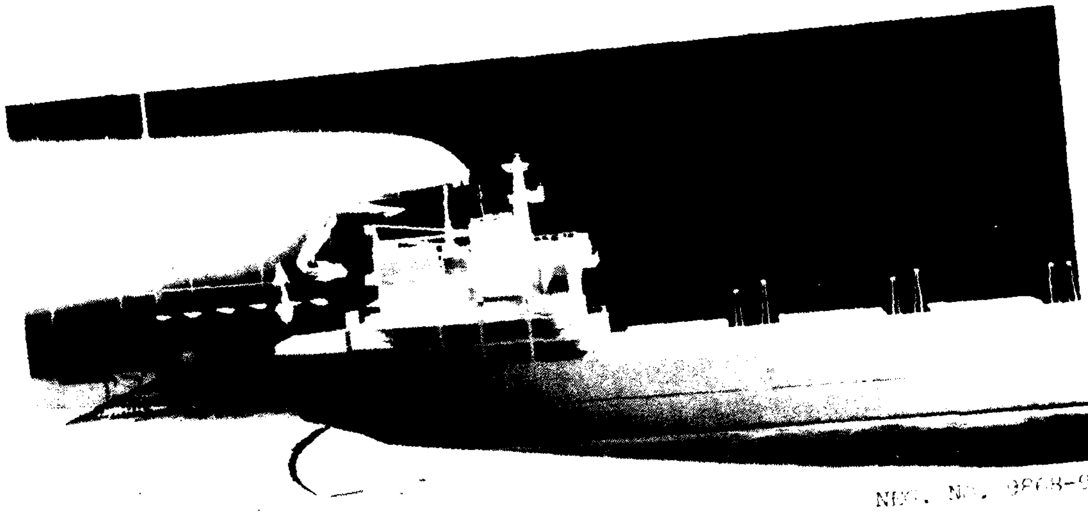
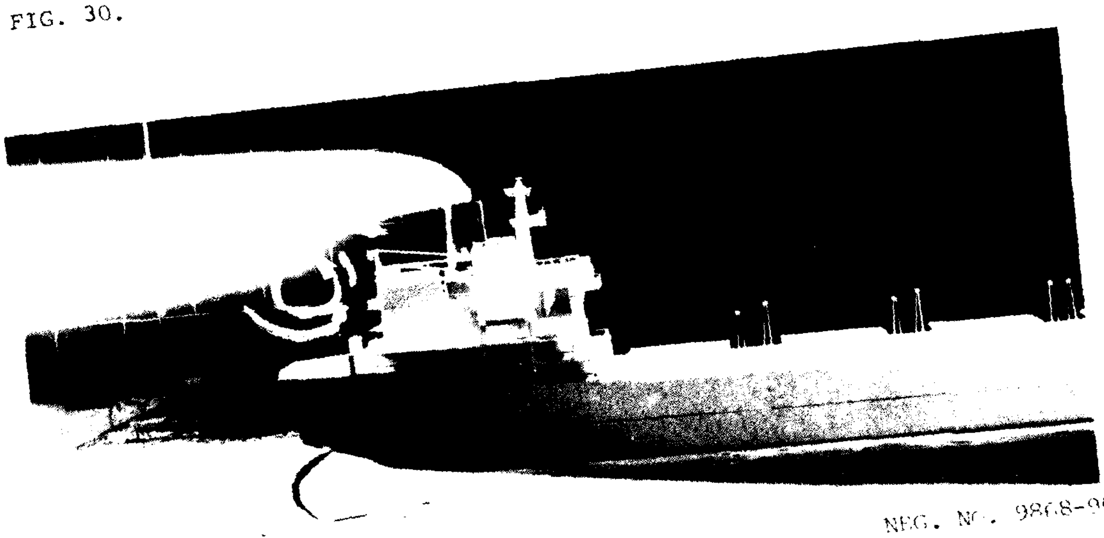


FIG. 29. NEG. NO. 9868-95



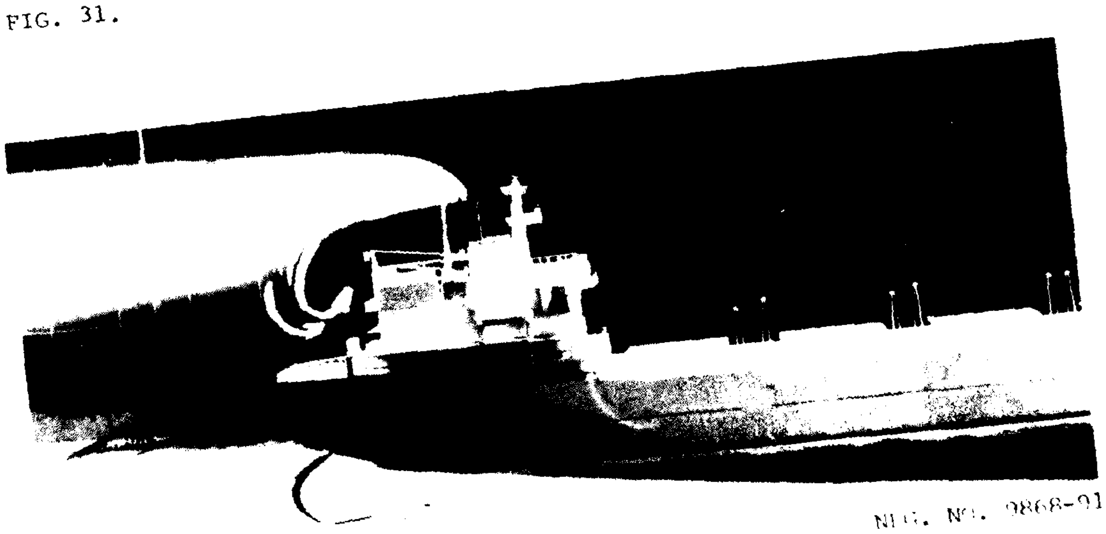
NEG. NO. 9868-97

FIG. 30.



NEG. NO. 9868-90

FIG. 31.



NEG. NO. 9868-91

FIG. 32.

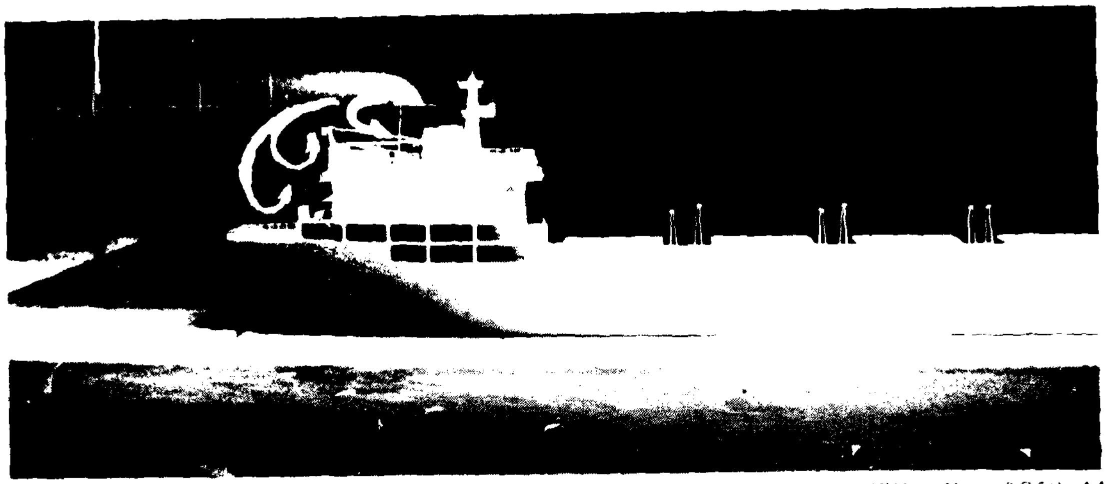


FIG. 33. NEG. NO. 9868-44

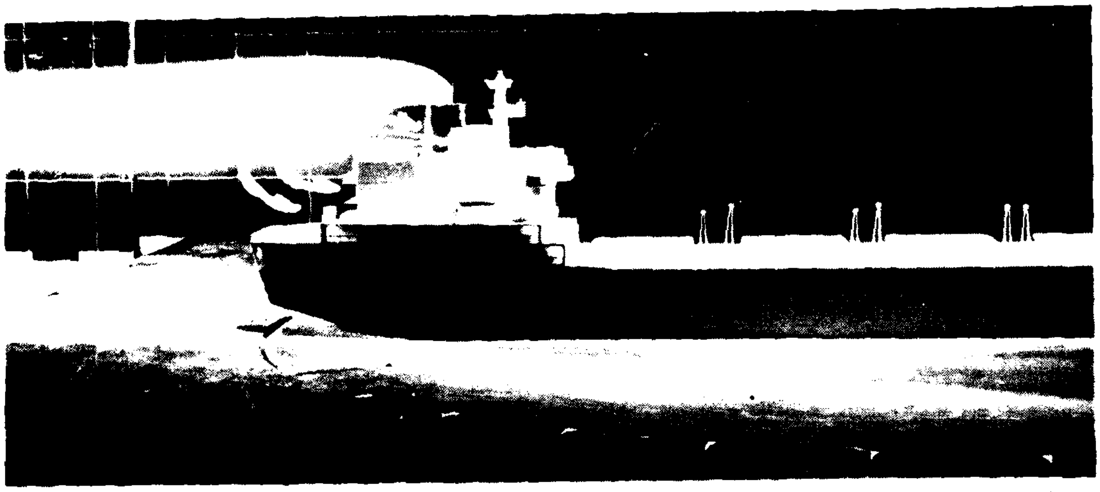


FIG. 34. NEG. NO. 9868-47

FIG. 35. NEG. NO. 9868-46

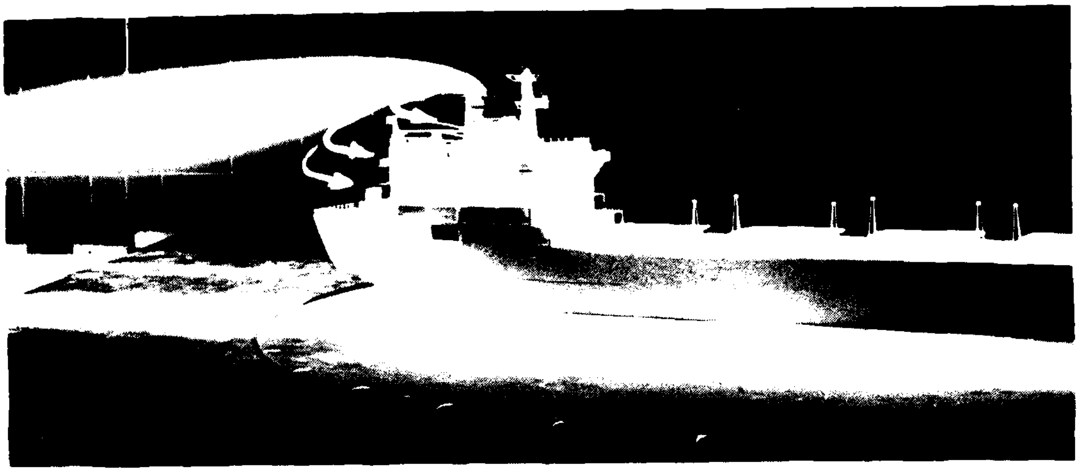


FIG. 36. NEG. NO. 9868-45

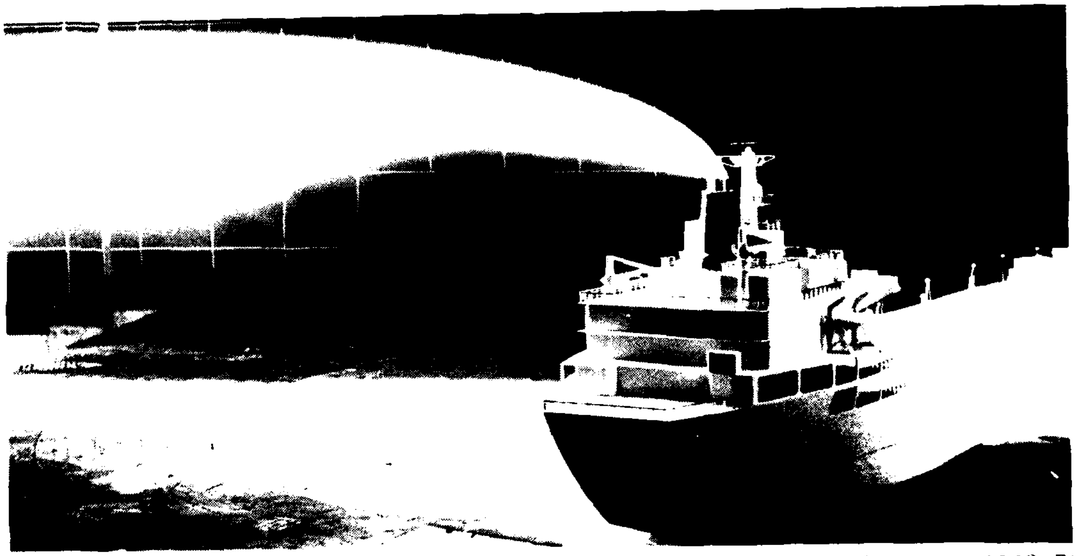


FIG. 37. NEG. NO. 9868-79

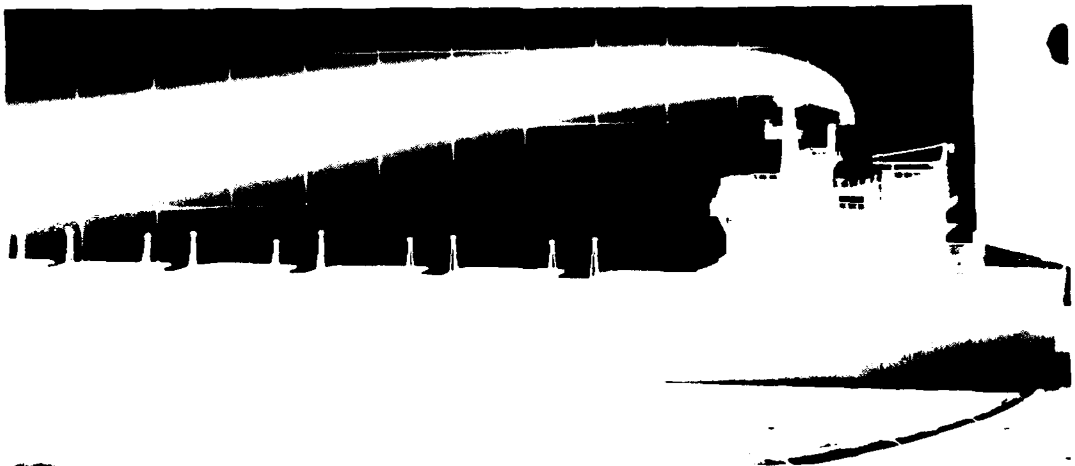


FIG. 38. NEG. NO. 9868-78

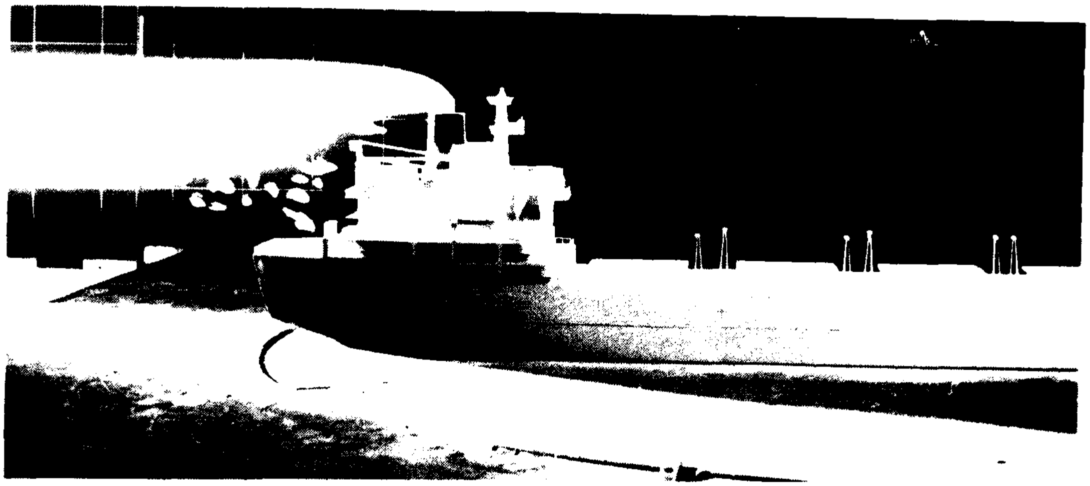


FIG. 39. NEG. NO. 9868-58

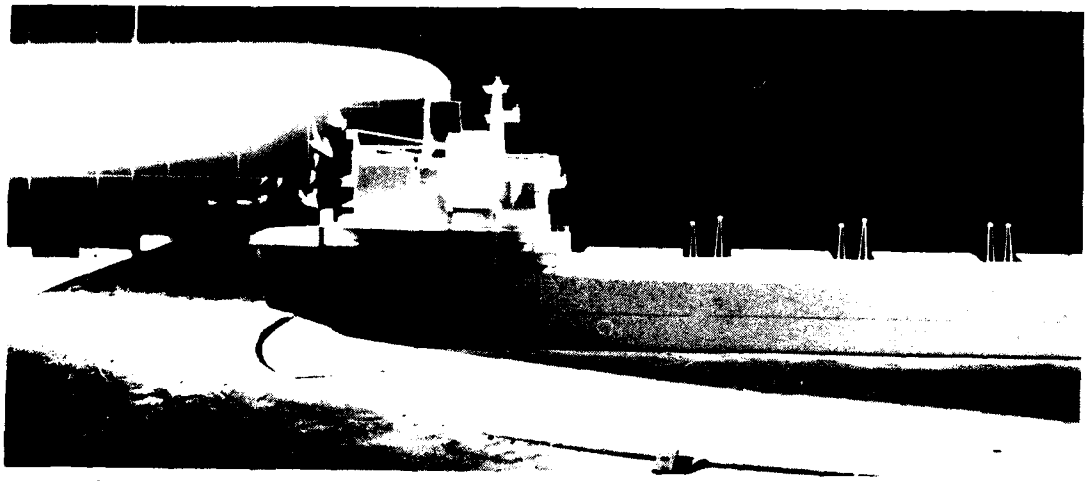


FIG. 40. NEG. NO. 9868-59

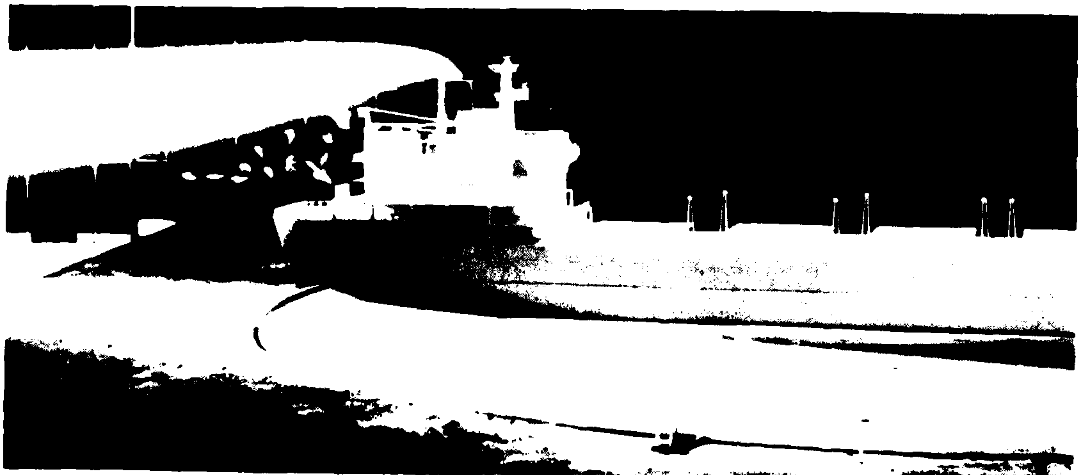


FIG. 41. NEG. NO. 9868-57

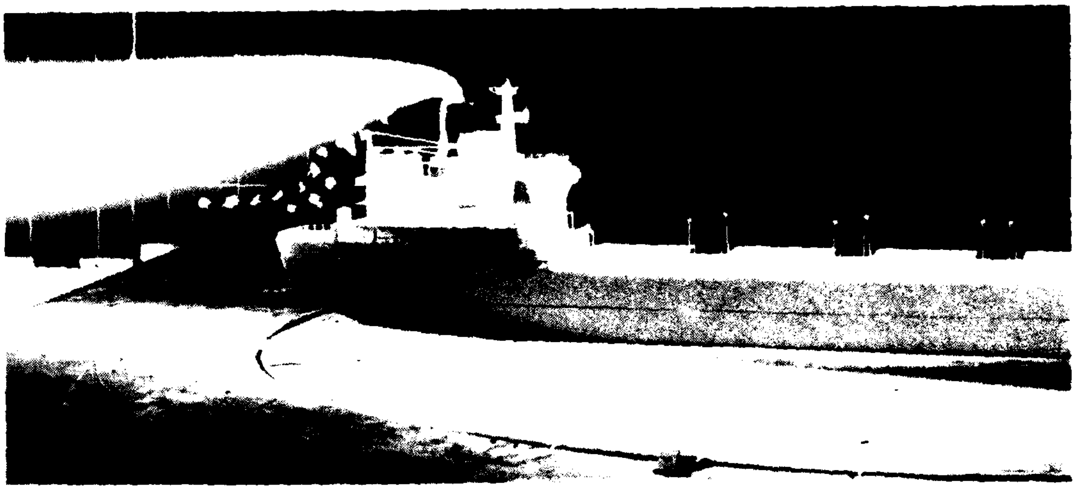


FIG. 42. NEG. NO. 9868-60

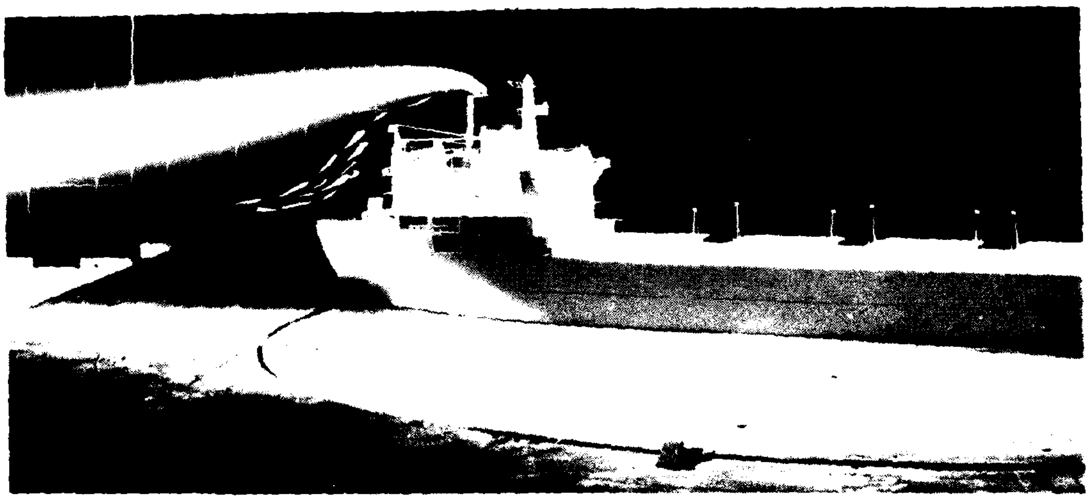


FIG. 43. NEG. NO. 9868-56

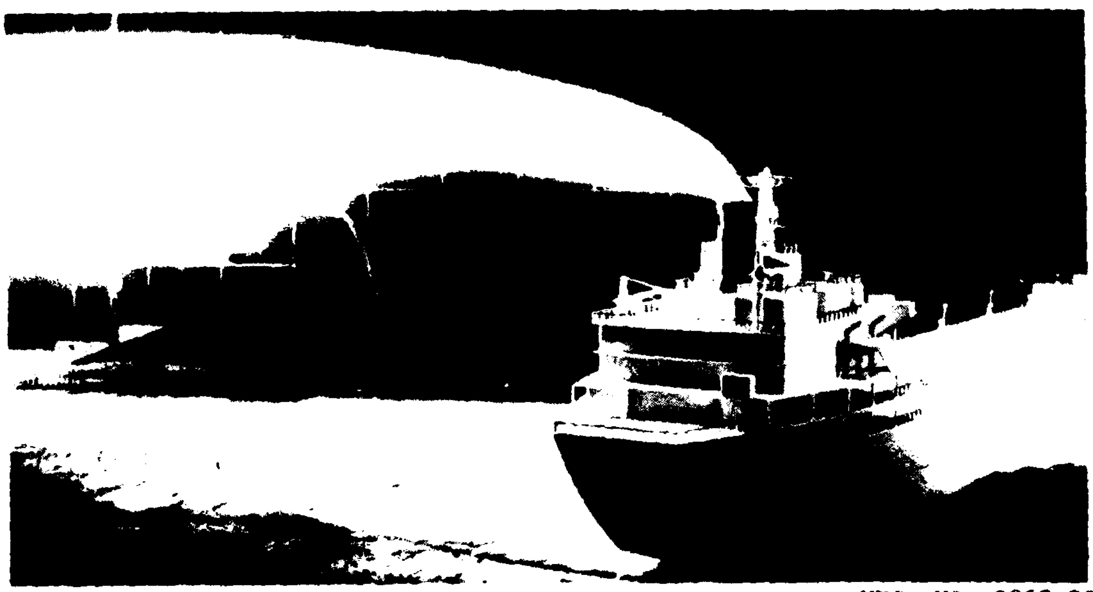


FIG. 44. NEG. NO. 9868-80

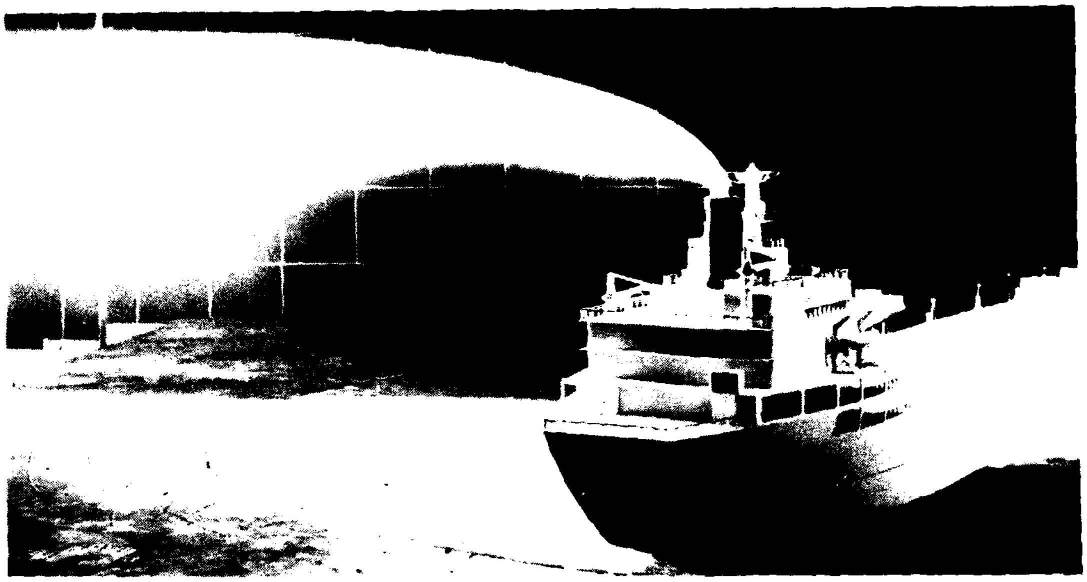


FIG. 45. NEG. NO. 9868-81

FIG. 46. NEG. NO. 9868-77

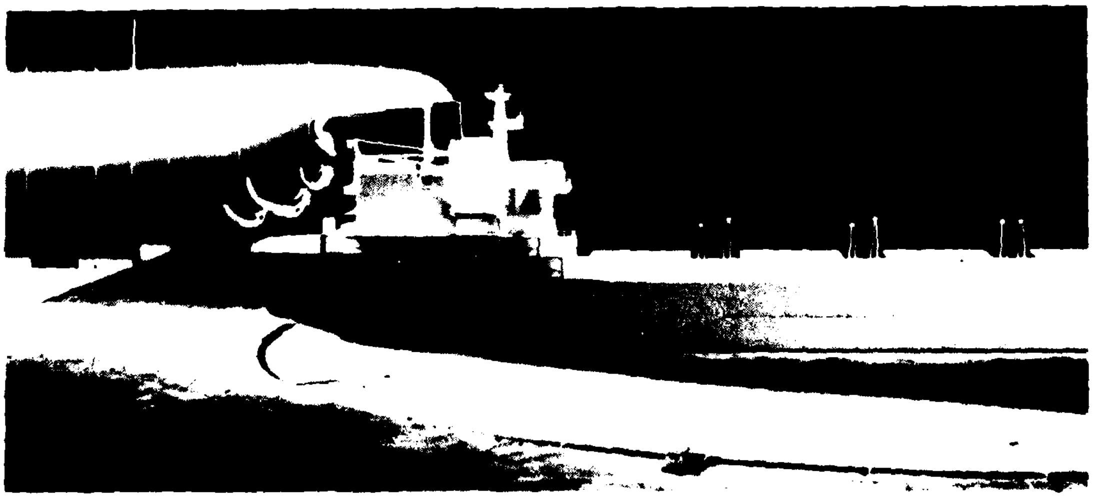


FIG. 47. NEG. NO. 9868-53

FIG. 48. NEG. NO. 9868-68

FIG. 49. NEG. NO. 9868-54

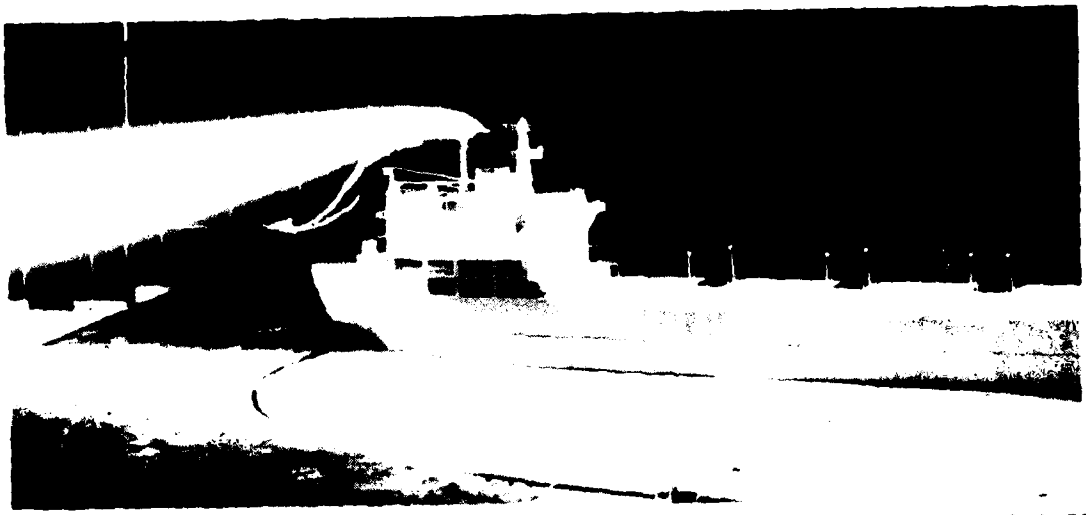


FIG. 50. NEG. NO. 9868-55

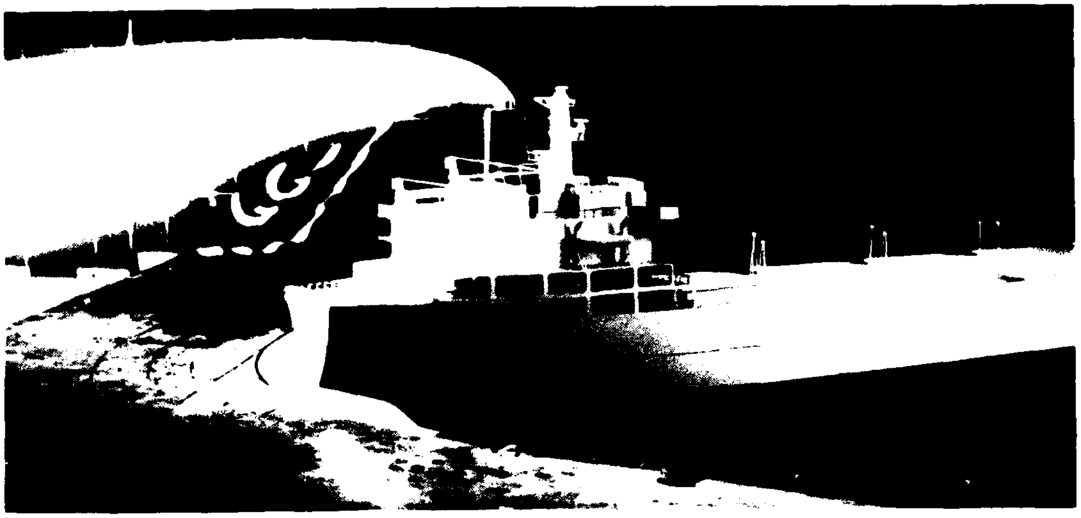


FIG. 51. NEG. NO. 9868-74

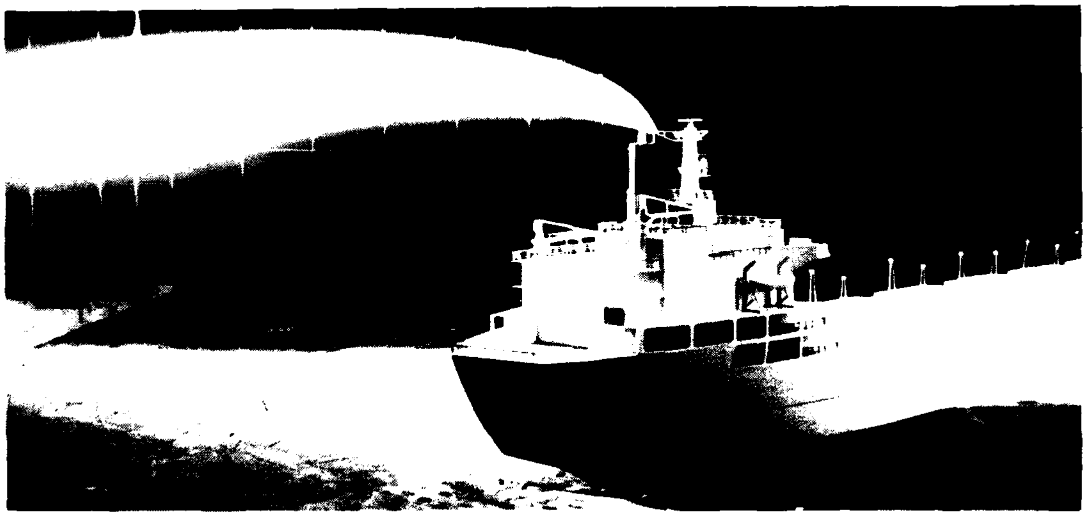


FIG. 52. NEG. NO. 9868-75

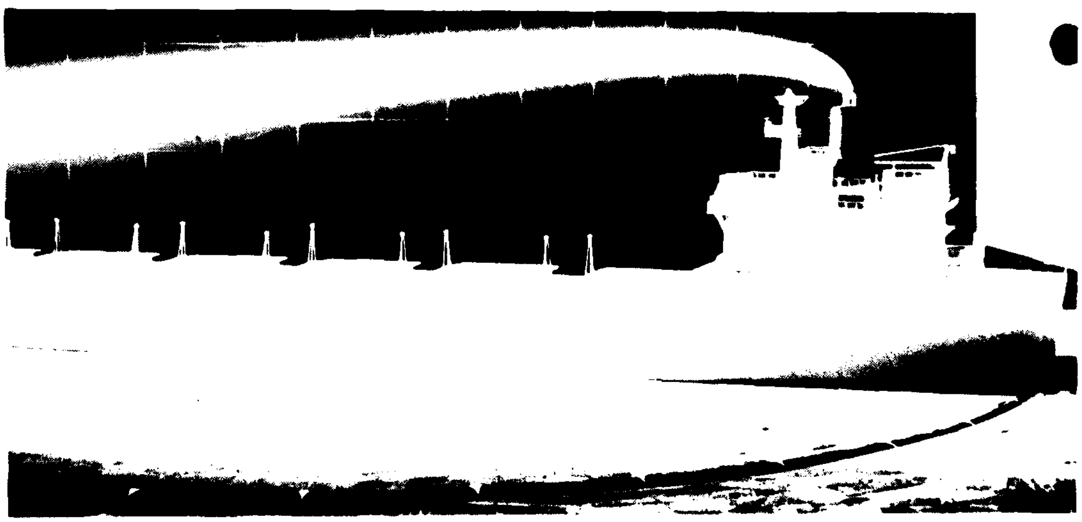


FIG. 53. NEG. NO. 9868-76

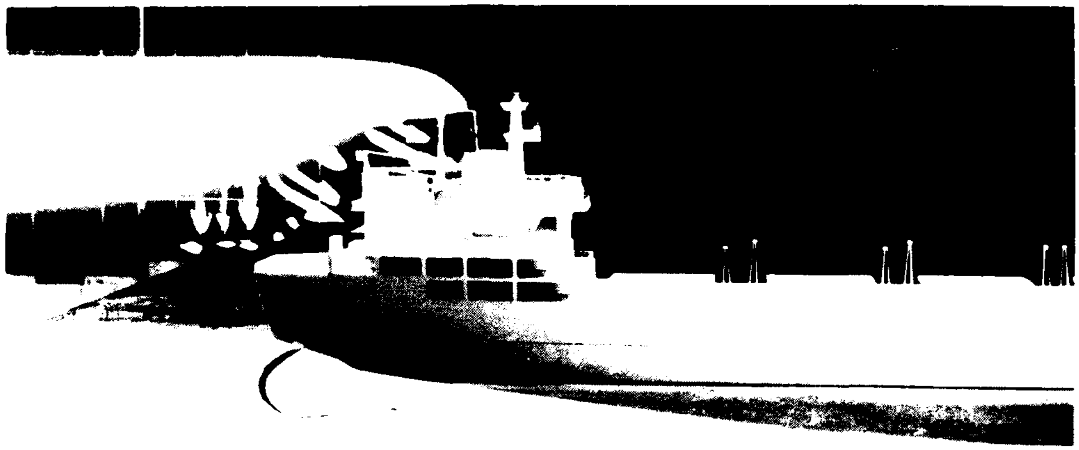


FIG. 54. [illegible]-92

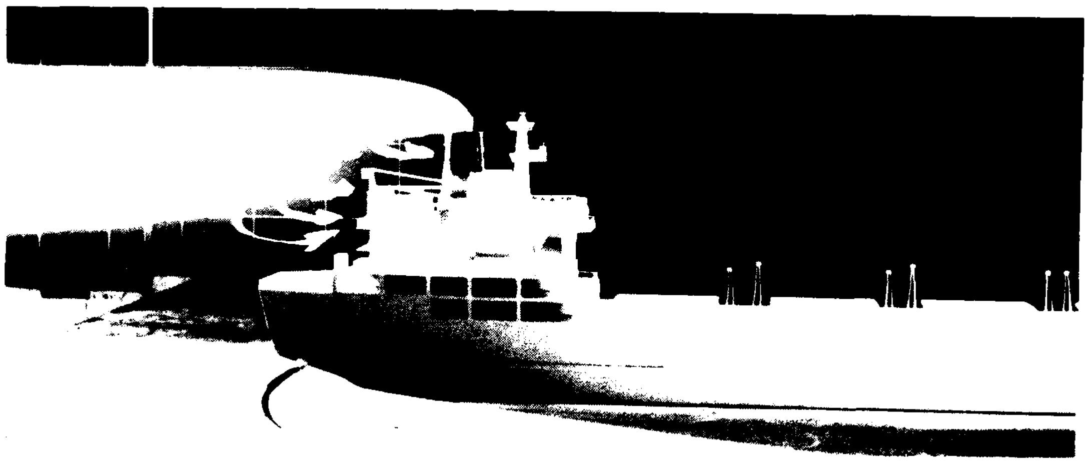


FIG. 55. [illegible]-89

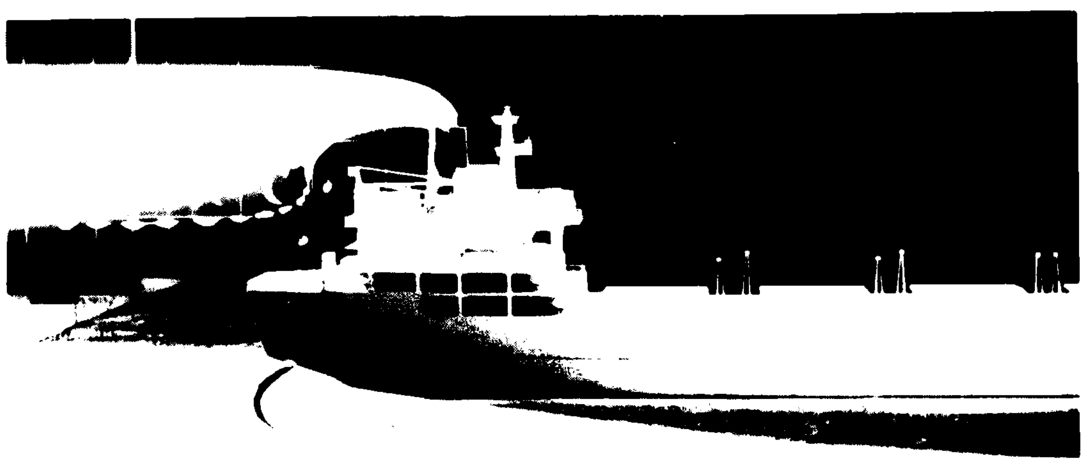


FIG. 56. NEG. NO. 9868-87

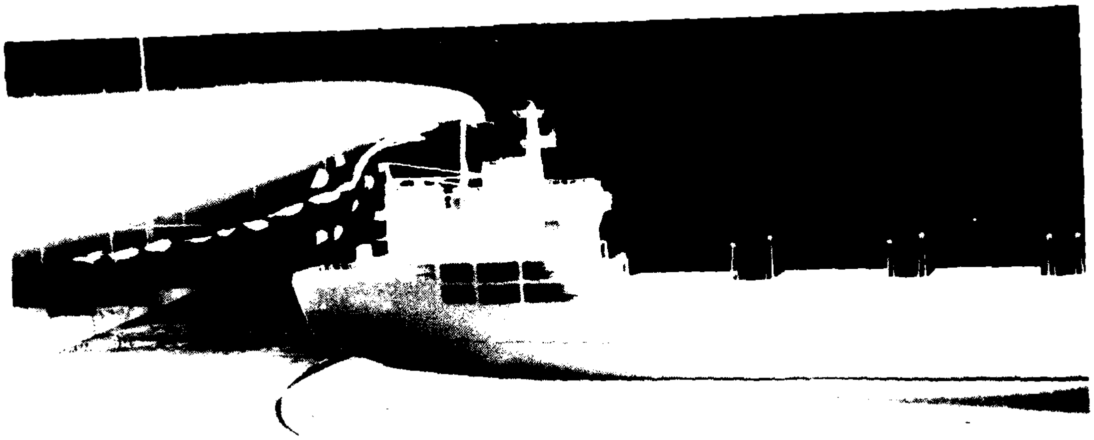


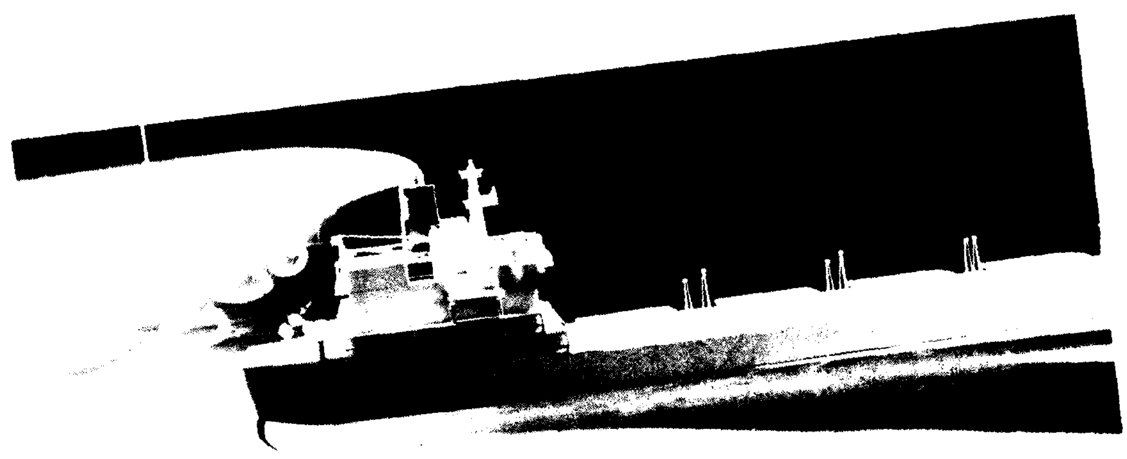
FIG. 57. NEG. NO. 9868-88

FIG. 58. NEG. NO. 9868-86

FIG. 59. NEG. NO. 9868-114

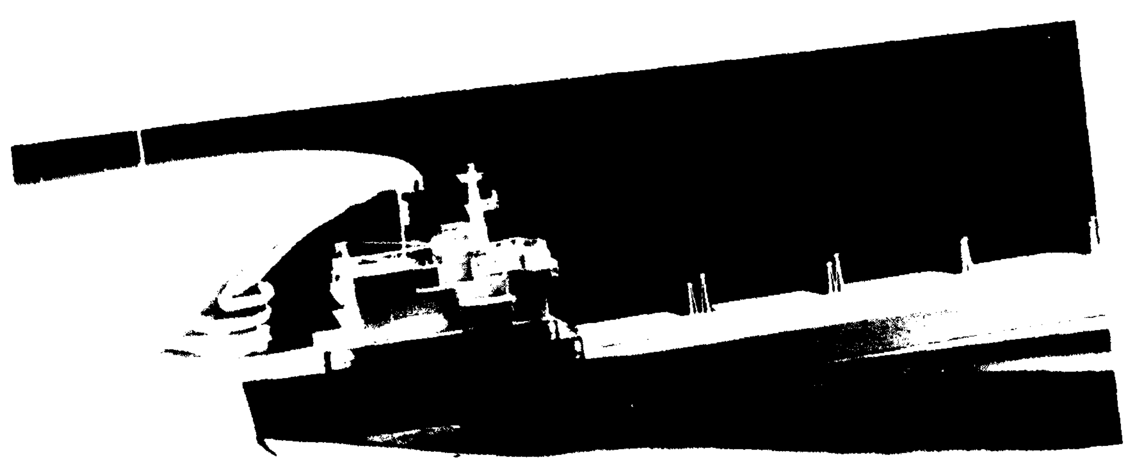
NEG. NO. 9868-113

FIG. 60.



NEG. NO. 9868-112

FIG. 61.



NEG. NO. 9868-110

FIG. 62.

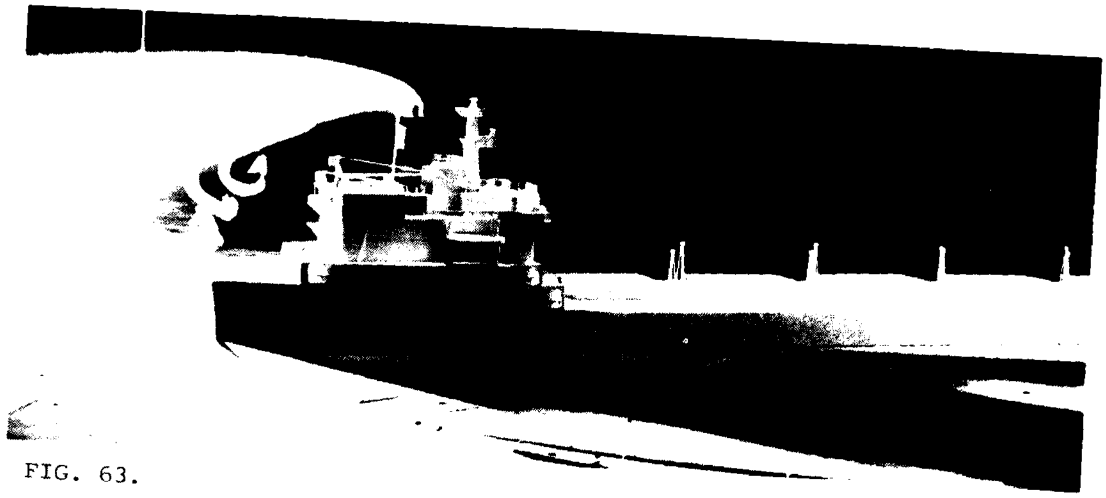


FIG. 63.

NEG. NO. 9868-108

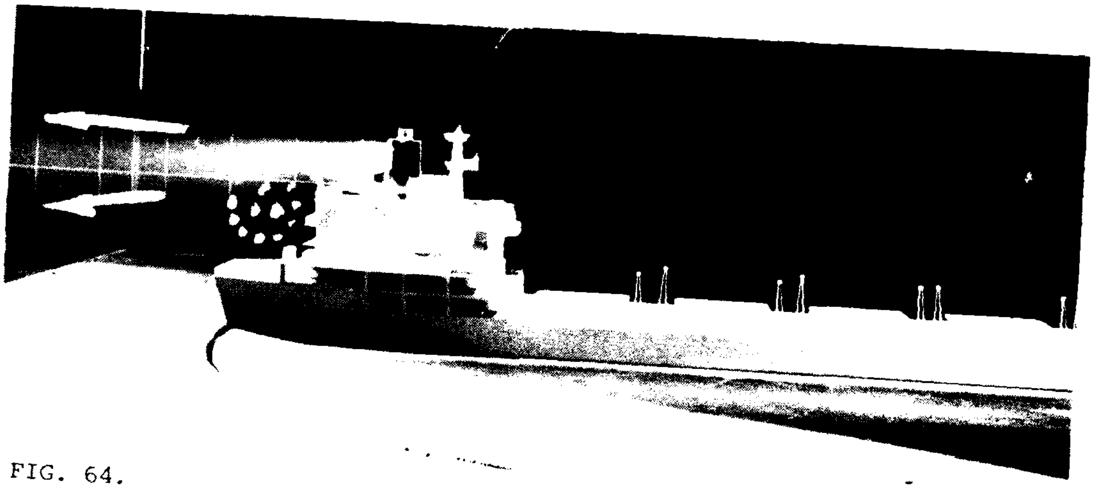


FIG. 64.

NEG. NO. 9868-115

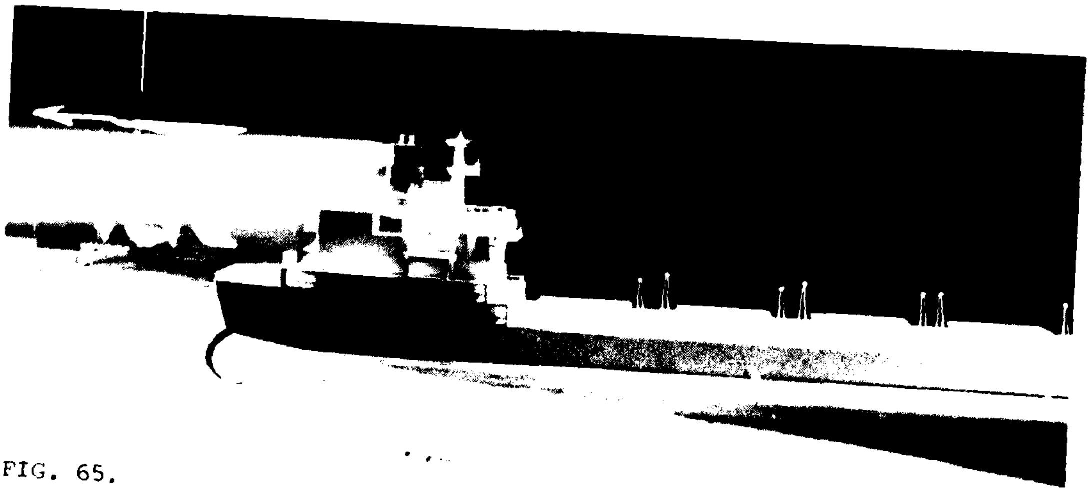


FIG. 65.

NEG. NO. 9868-118

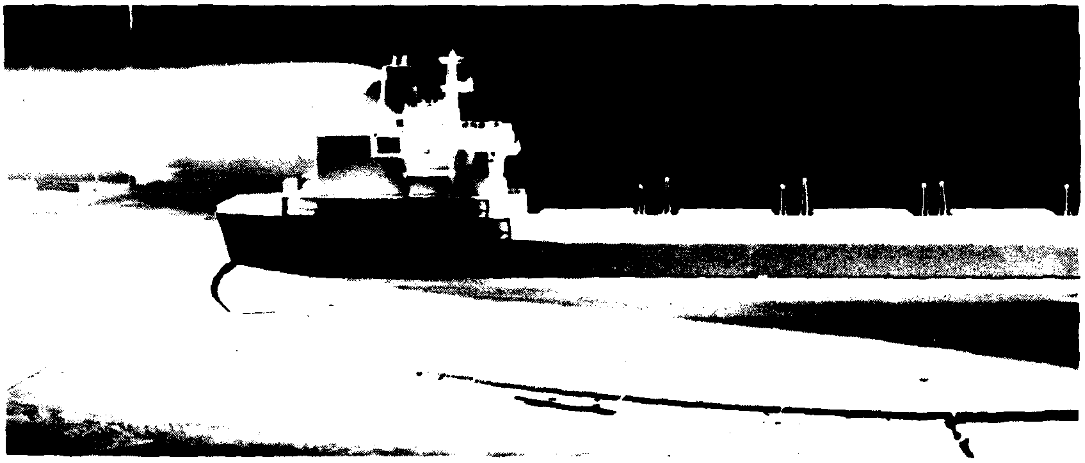


FIG. 66. NEG. NO. 9868-119

FIG. 67. NEG. NO. 9868-120

FIG. 68. NEG. NO. 9868-121

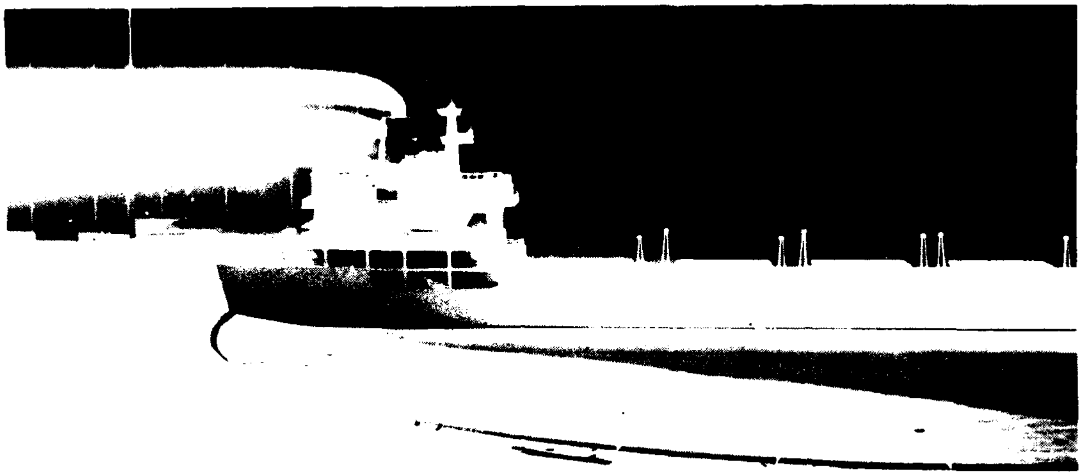


FIG. 69. NEG. NO. 9868-122

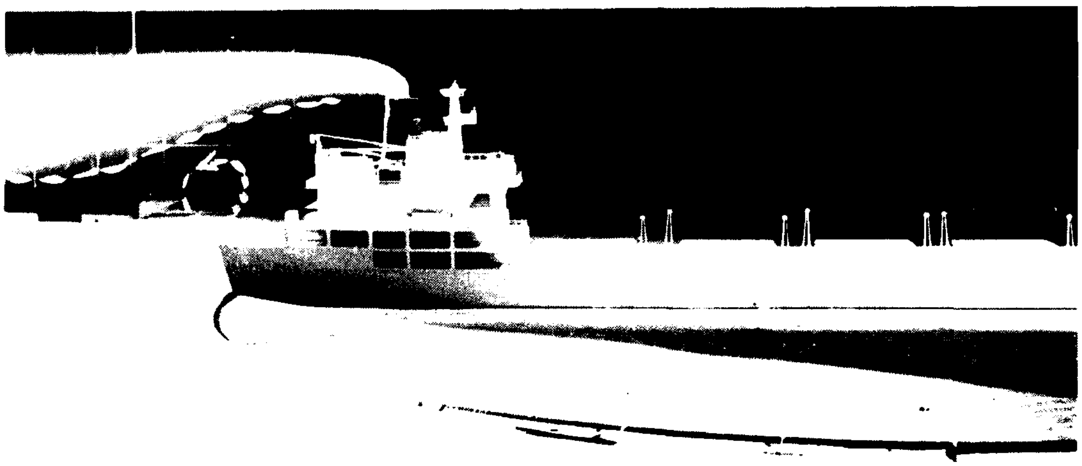


FIG. 70. NEG. NO. 9868-127

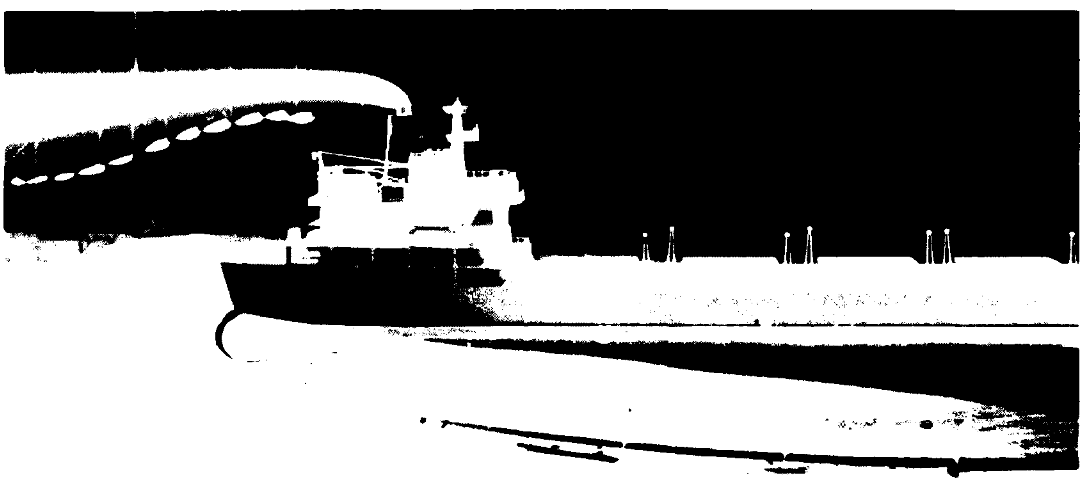


FIG. 71. NEG. NO. 9868-125

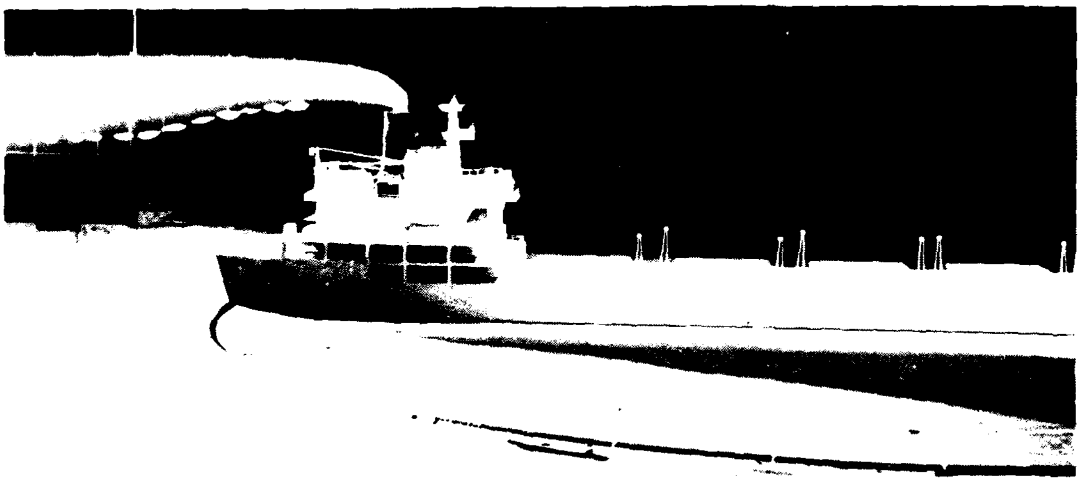


FIG. 72. NEG. NO. 9868-123

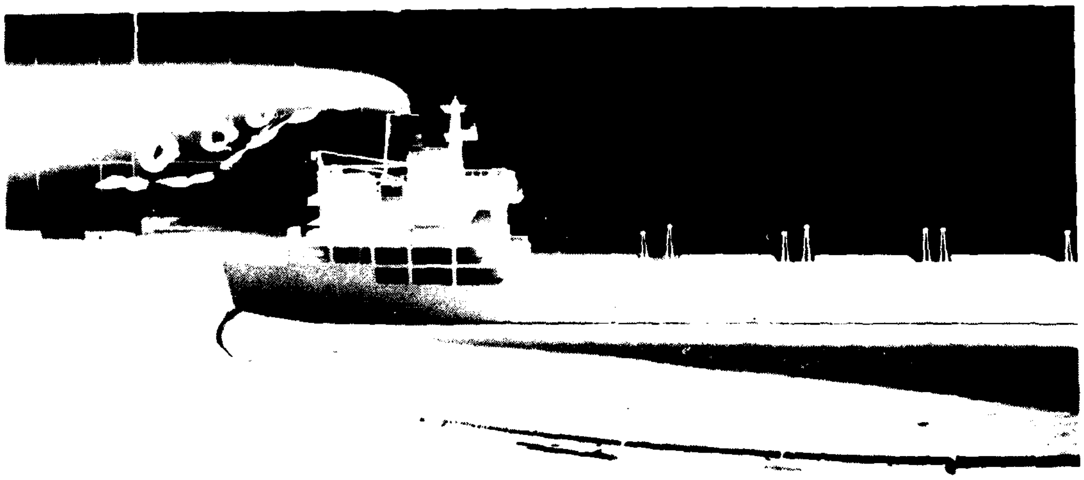


FIG. 73. NEG. NO. 9868-126

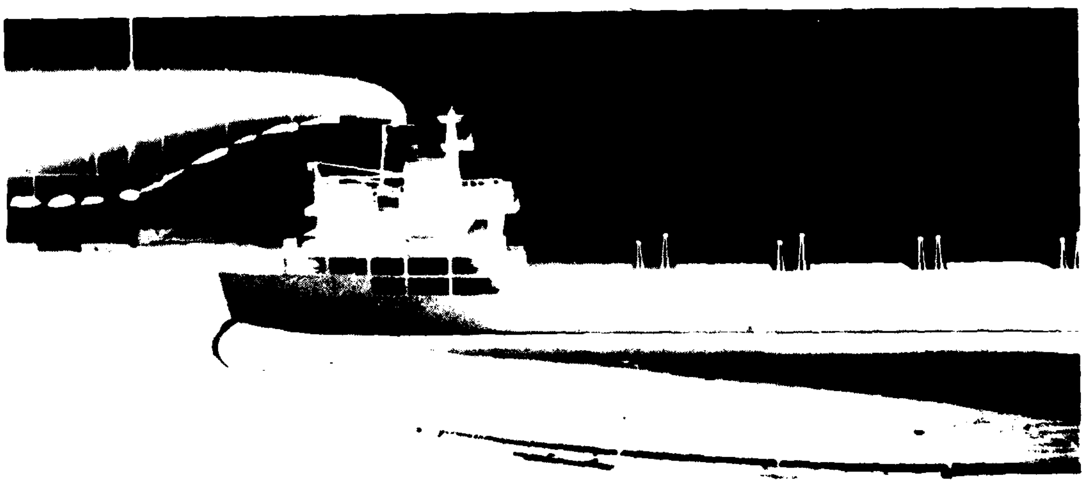
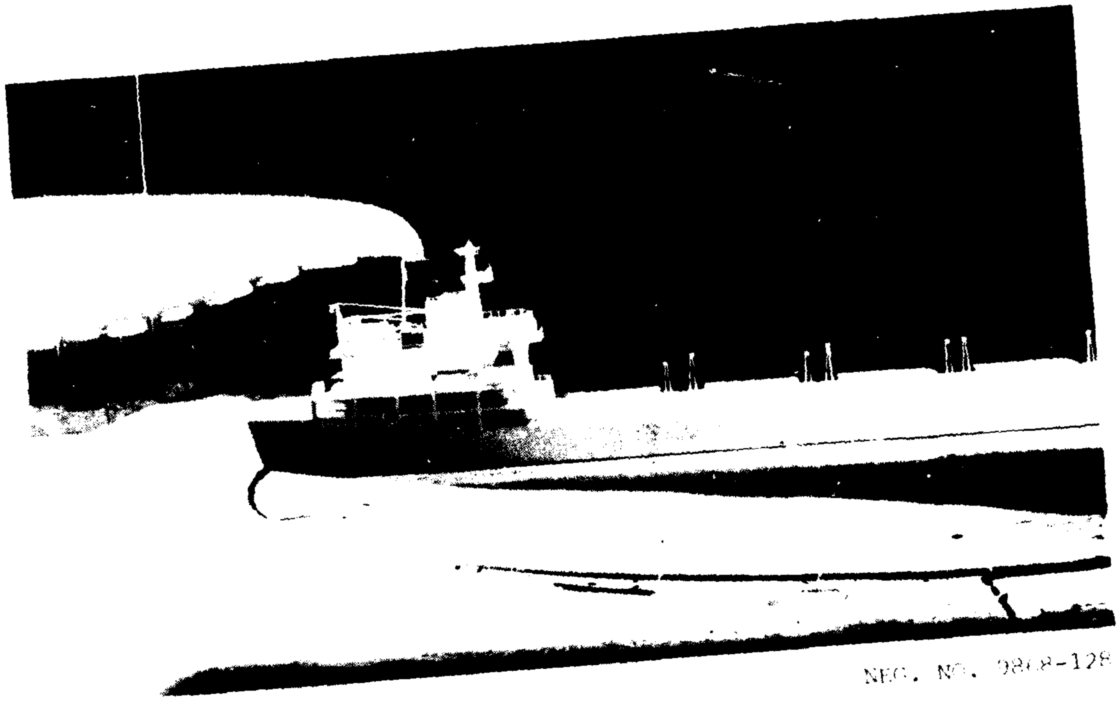
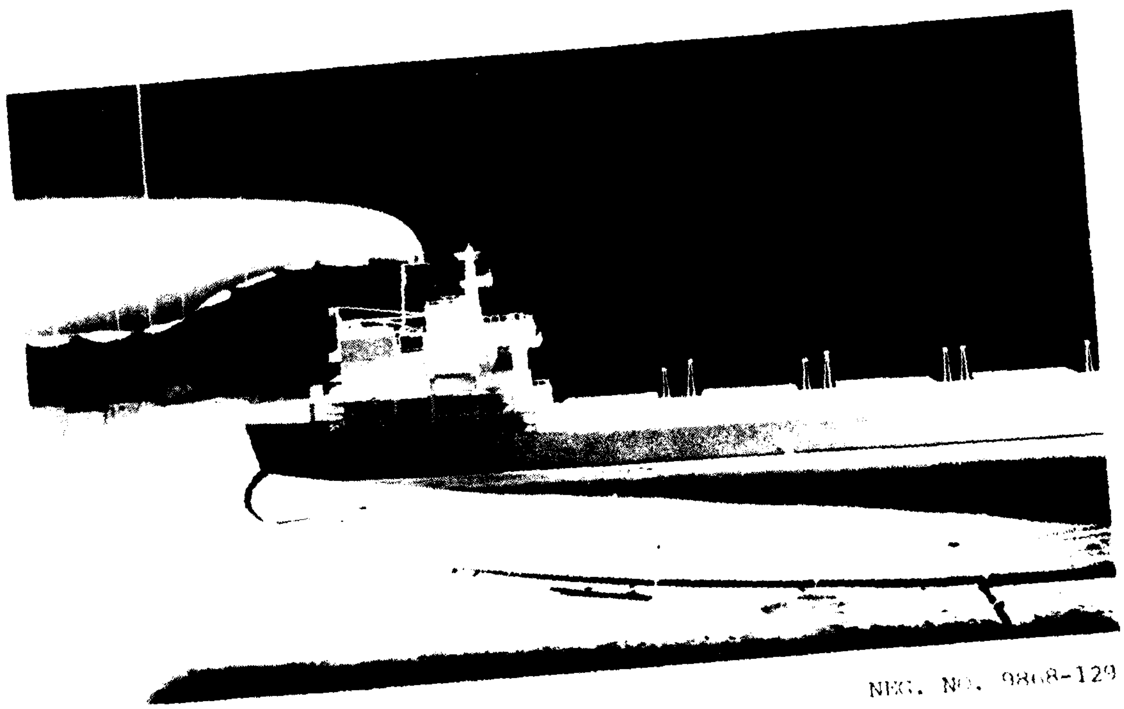


FIG. 74. NEG. NO. 9868-124



NEG. NO. 9868-128

FIG. 75.



NEG. NO. 9868-129

FIG. 76.

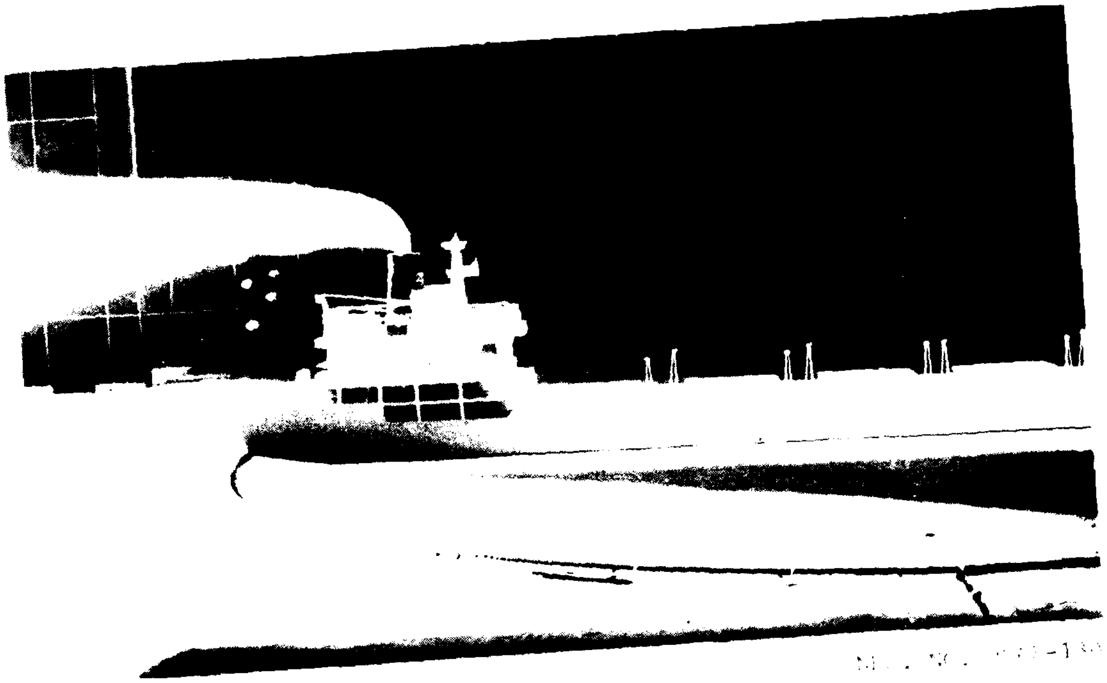


FIG. 77.

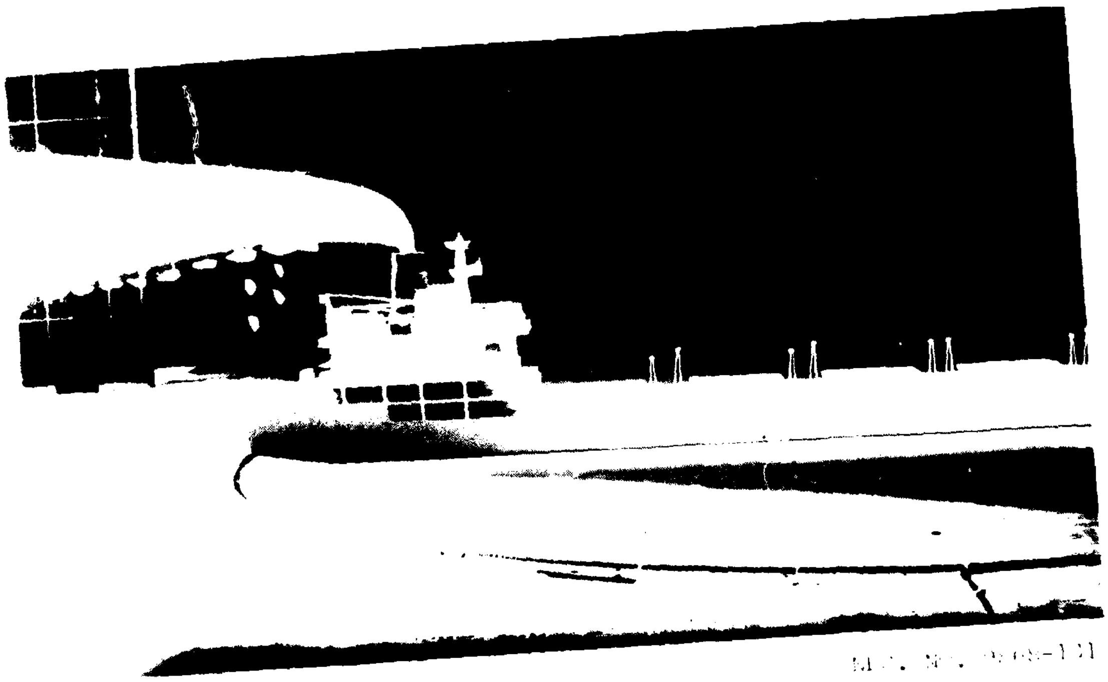


FIG. 78.

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